

SCHOOL OF ADVANCED AIR AND SPACE STUDIES

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**Logging the JSF:
Acquisition Logistics and Fleet Management for Modern
Fighters**

by

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In Partial Fulfillment of the Graduation Requirements

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The undersigned certify that this thesis meets masters-level standards of research, argumentation, and expression.

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(Date)

Lieutenant Colonel John G. Terino

(Date)

Disclaimer

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Preface

In various assignments during my 14-year Air Force career, I have developed logistics policies as a Pentagon staff officer and orchestrated logistics in support of wing-level operations as a squadron maintenance officer. While serving as an aircraft maintenance unit (AMU) flight commander at Nellis AFB, I became intrigued by the USAF aircraft sustainment process as a result of facing daily operational challenges caused by the budget shortfalls of the late-1990s. As I watched immensely talented, dedicated, and innovative young maintenance troops struggle to meet constant mission demands with dwindling resources, I started to think critically about ways to resolve the organizational tension between the Air Force's procurement, operations, and logistics communities. How do we balance requirements among the three to arrive at a rational algorithm for fleet management?

The F-16 and F-35 present two case studies with high relevance to answer this multifaceted question. The sustainment crisis endured by aircraft weapon systems during the 1990s highlights the need for innovative ways to forecast requirements and optimize scarce life-cycle-sustainment funding. As the USAF continues to meet constant operational demands in the Global War on Terror, aircraft life-cycle sustainability will become increasingly vital to the employment of airpower across the spectrum of warfare.

Several people deserve heartfelt thanks for helping me complete this thesis. Dr. Stephen Chiabotti has been the quintessential mentor, advisor, and teacher in guiding me along this tedious journey. Lieutenant Colonel John Terino was invaluable as critical logistics mind to test my propositions. Special thanks go to "His Royal Chiefship" Bob Laymon of the Raytheon Aircraft Corporation for his perspective on aircraft procurement as well as the maintenance *ethos* and Mr. Mike Wasson, AETC Studies and Analysis, for his patient instruction on the "art and science" of sensitivity modeling. Colonel Rick Matthews, Joe Seawell, and Steven Schumacher, Lieutenant Colonels Carl Buhler and Brian Manes, Majors Ronald Jolly, Jason Childs, Timothy Kirk, George Govan, and Shannon Whited, along with Captains Kenyon Bell and Willie Bohles provided immeasurable real-world perspectives germane to this interdisciplinary problem. While this project is immeasurably improved as a result of their assistance, any shortcomings discovered in the analysis and conclusions are solely the fault of the author.

Most importantly, my God and my family (Natalie, Trey, and Ian) deserve my most sincere praise and thanks, respectively, for once again providing me the strength, inspiration, and support to pursue my life's work in the profession of arms.

Abstract

Within the US Air Force, acquisition, operations, and logistics communities collectively face a perplexing question: *What is the best way to plan the acquisition and life-cycle sustainment of a fighter aircraft fleet?* To find the answer to this question the following thesis attempts to derive lessons learned from case study analysis to develop a new methodology for future use.

Aircraft fleet size, in an acquisition program, is determined by assessing the capabilities necessary to meet current and future operational readiness demands. Aircraft sustainment, although equally important, is typically not considered during early procurement planning due to the difficulty in forecasting the sustainment infrastructure necessary to mitigate effects caused by aging and changing operational requirements. At best a nebulous endeavor, sustainment forecasting is affected by the myriad of dynamic organizational, technological, and budgetary influences caused by rigid DoD acquisition processes and inflexible Congressional appropriations cycles.

Risk trade-offs between aircraft performance and costs variables directly influence the operational employment and sustainability of a weapon system over its service life. Quantitative modeling, through sensitivity analysis, provides a method to assess the unforeseen effects of these influences, such as peacetime/wartime attrition, fiscal year budget shortfalls, operational employment variations, and procedural shifts, on a weapon system's service-life viability. By measuring the extent that operations and logistics factors have on sortie capacity through sensitivity modeling, acquisitions planners can better validate initial service-life projections, determine fleet size requirements, and avert mid-life-cycle sustainability crises.

This thesis introduces a counter-intuitive approach to optimizing life-cycle sustainment funding over an aircraft's projected service-life. The Total Life-Cycle Sustainment (TLCS) model is derived based on the following two assumptions: 1. a positive correlation exists between aircraft age and sustainment costs and 2. a highly-reliable aircraft's mission capability performance is tailorable to operational flying-hour program requirements. Evidence from the life-cycle performance of the F-16 dual-role fighter serves as a foundation to advocate utilization of the TLCS approach as a framework in on-going and future acquisition and sustainment planning for the F-35 Joint Strike Fighter (JSF). If adopted, the TLCS approach can better leverage time and early life-cycle reliability through the use of tailored performance metrics, constant reinvestment of accrued savings, and just-in-time support logistics support to assure adequate sustainment throughout an aircraft's service-life.

Introduction

Technology is messy and complex. It is difficult to define and to understand. In its variety, it is full of contradictions, laden with human folly, saved by occasional benign deeds, and rich with unintended consequences ... History does not repeat itself in detail, but drawing analogies between the past and present allows us to see similarities. For this reason, generals study military history, diplomats the history of foreign affairs, and politicians recall past campaigns. As creatures of a human built world, we should better understand its evolution.

—Thomas P. Hughes
How to Think About Technology and Culture

Prior to presenting the main body of this thesis, the following summary provides the framework utilized to conduct the research and present the findings represented in this project. This summary is intended to bound the research problem and provides an overview of the composition of the thesis' main body.

Research Methodology

How do sortie generation, supply, and maintenance factors affect weapon system fleet size and life-cycle sustainability? More importantly, can imaginative planning, derived from sensitivity analyses and experience, affect economies in the management of aircraft fleets? I plan to use historical data from the F-16 aircraft procurement effort as evidence to support my assumptions regarding the importance of incorporating logistics

efficiency/reliability into the front-end of acquisition programs. As aircraft procurement efforts become more expensive and politically contentious, early efforts to streamline logistics and maintenance costs could positively affect life-cycle weapon system sustainment. The F-35 Joint Strike Fighter (JSF) program is still in the early phases of its acquisition cycle and amenable to recommendations which may point to inefficiencies in the program. By conducting a look-ahead into F-35 operations and logistics requirements based on historical data and future assessments, AF acquirers and programmers can better plan for future production and sustainability challenges. This study offers a counterintuitive approach to meeting life-cycle sustainment requirements. By varying maintenance metrics standards based on flying-hour program requirements, accrued surpluses through reinvestment provide a funding stream to address future aircraft aging and deterioration. Given the recent unpredictability of DoD fiscal policy and budget priorities, a self-generating sustainment methodology is useful to provide total life-cycle sustainment support to next-generation aircraft weapon systems.

Assumptions and Limitations

This thesis is framed by two important assumptions: 1. the positive correlation between aircraft age and sustainment costs and 2. the variability of a highly-reliable weapon system's mission capability performance based on operational flying-hour program requirements. While these assumptions are fairly obvious, they establish a baseline from which to develop a thesis and advocate the proposed Total Life Cycle Sustainment (TLCS) framework. However, because the framework is dependent on the success of the military-industrial-complex to provide increasingly innovative and reliable weapon systems, its application is limited to the context of a western military supported by a civilian industrial base. Therefore the proposed framework's utility is contextually restricted to military organizations which possess an autonomous industrial capability to develop, employ, and sustain military power.

Overview

This thesis uses an instructional, historical, analytical approach to answering the aforementioned research question.

Chapter 1 provides an instructional overview of the Air Force wing organization. The chapter provides an explanation of the roles and challenges of wing operations and maintenance functions and discusses the required interdependence necessary to accomplish the wing warfighting mission.

Chapter 2 provides a historical summary of the F-16 weapon system program. Beginning with its origins in the early 1970s, the chapter traces the aircraft's evolutionary development through the lean 1990s and into the 21st century. Particular emphasis is placed on the increasing mission demands of the weapon system as it expanded from an air-to-air concept-design to a dually-employed-weapon-system.

Chapter 3 begins with a historical summary of early F-16 decision-making regarding sustainment provisioning and forecasting techniques. It then shifts to analyzing the causal factors to the declining mission capability performance during the 1990s. The chapter offers actual accounts from maintenance and logistics personnel faced with meeting these pressing mission demands despite a dwindling sustainment infrastructure.

Chapter 4 defines the key maintenance metrics used to assess aircraft mission readiness and introduces quantitative modeling techniques as a tool to measure the sensitivity of fleet sortie capacity to subtle fluctuations in operational and maintenance indicators.

Chapter 5 provides an overview of the JSF program to include its evolutionary logistics concepts and technologies. A discussion of JSF recent procurement challenges follows the overview and highlights the need for a methodology for planning the life-cycle sustainment of the weapon system. The TLCS framework is proposed and followed by recommendations for necessary organizational and procedural changes to enable its effectiveness.

The thesis' conclusion synthesizes the key aspects of chapters 1 through 5 and examines the implications for its findings.

Rhetoric vs. Reality?

The TLCS model presented in this thesis is intended to provoke critical thinking and dialogue between disparate functional communities within the Air Force concerning

the implications and benefits of a total life-cycle approach to weapon system sustainment. While many will find bureaucratic pitfalls and limits to the full implementation of the TLCS methodology, the framework challenges the existing execution-year sustainment mindset, which incurs significant risk to attain projected weapon system service-life goals. Admittedly, the TLCS will, in all likelihood, fall short of passing the various procedural *litmus* tests unique to particular *tribes* of the vast DoD bureaucracy. Despite this reality, intensive analysis is still warranted and necessary to resolve the larger problem of sustaining vital military weapon systems for employment in defense of the United States.

Chapter 1

Men, Machines, and Metrics

I believe the two hardest things we do in this command are to fly and fix airplanes ... the flying part of it we're pretty darn good at and we've demonstrated that over the years ... the fixing of airplanes has been one of those things that depend on the spirit, proficiency, and capability of the maintainers.

*Gen John P. Jumper—April 2000
Commander, Air Combat Command*

The modern-day Air Force wing organization is a vast enterprise comprised of various units which contribute to the operational readiness necessary to meet peacetime training and contingency warfighting objectives. The “health” of the wing organization is determined by assessing readiness criteria such as the inventory of proficient pilots and maintainers capable of performing the assigned missions and functions. The wing’s mission is to attain an adequate state of readiness, which in the USAF warfighting context can be divided into two distinct subcategories: current military capabilities and the production of future capabilities.

The primary factors contributing to *current* capabilities include the proper number of trained personnel to accomplish the warfighting mission and the reliability of equipment and supplies to support warfighting objectives.¹ These inputs produce the required number of combat sorties needed to support combatant commander objectives. On the other hand, the production of *future* capabilities is an equally critical mission of the wing organization. Whereas the metrics for determining whether a wing has met

¹ Carl J. Dahlman and David E. Thaler, *Assessing Unit Readiness--Case Study of an Air Force Fighter Wing*. RAND—Project Air Force, 2000, n.p. On-line. Internet, accessed 1 February 2005 available from <http://www.rand.org/publications/DB/DB382/>.

current military capabilities are quite clear, the guidance on metrics determining future operational readiness is less. These more nebulous criteria include the measurement of the rejuvenation of human capital through on-the-job-training (OJT) within the pilot and maintenance communities. A common occurrence within most wings is the tendency to trade off the development of future capabilities for *robusting* current ones to meet pressing contingency operations. While this approach satisfies short-term wing objectives, it ultimately cripples long-range warfighting capabilities by stifling training for inexperienced personnel and ignoring the all-important life-cycle maintenance of combat aircraft.

Pilots, Maintainers, and Sorties

Pilot training is a critically important task performed by operational units within the Air Force wing. The pilot training flow represents the wing's combat capability lifeline and determines the tempo of steady-state wing sortie production. Not only does the wing need sorties to train inexperienced pilots in order to facilitate the flow of training, but it also needs to maintain the proficiency of veteran pilots who serve as instructors and the front line of expertise to meet current warfighting requirements.²

The USAF pilot training system is an intricate mix of formal and on-the-job training that measures an individual pilot's proficiency based on the successful completion of training events and the attainment of flying-hour milestones. From the time an inexperienced pilot completes undergraduate pilot training, he/she undergoes a stream of training opportunities to expand and refine combat airmanship skills. Starting with a brief course at one of several field training units which provide weapon-system specific instruction, the new pilot continues to undergo mission qualification training (MQT) at his/her first assignment leading to the coveted combat mission ready pilot designation (CMR-N). Once deemed *mission ready*, the still inexperienced pilot continues training to become an instructor pilot (IP), flight lead (FL), and/or mission commander (MC). Once this second echelon of training is completed, the pilot is considered experienced and receives the (CMR-E) designation. As such, he/she is

² Dahlman, on-line, Internet, available from <http://www.rand.org/publications/DB/DB382/>.

qualified to teach CMR-N pilots and is considered the linchpin of the unit's combat capability.

A constraining factor that presents significant challenges to wing readiness is the gain-to-loss ratio that occurs as a normal function of the military assignment system. Whereas, in theory, assignment policy stipulates that experience lost by departing personnel should be replaced on a per capita basis, the stark reality is that the squadron is usually in a continual cycle of trying to mitigate the revolving-door effects of never-ending personnel rotations. This dilemma presents significant challenges to the wing's sortie production capability by demanding a constant rate of training sorties for the continuous influx of inexperienced pilots. The imbalance created by this organizational culture places a burden on the wing's maintenance and sortie-generation complex to produce sorties to rectify this capability gap while maintaining the health of the aircraft fleet.

Another important function of the air force wing is the training of proficient maintenance crews capable of generating the required number of sorties to support wing pilot training and to maintain the health of the assigned aircraft fleet. Much like pilots, maintenance crews require on-the-job training, beyond formal education experiences, in order to perform as mission-ready technicians. In accordance with recent revisions of Air Force Instruction 36-2618, maintenance technicians are categorized by tiers: Airman, Non-Commissioned Officer (NCO), and Senior Non-Commissioned Officer (SNCO).³ The SNCOs form "a critical component of the Air Force's ability to project air power" through their leadership within the maintenance career field."⁴ Junior airmen, on the other hand, are designated to "a learning capacity" and are expected to develop their professional skills and knowledge until as senior airmen; they become "skilled technicians and trainers."⁵ The bread and butter of the maintenance complex is the NCO tier which performs the majority of maintenance tasks and instructs inexperienced junior airmen.

³ Air Force Instruction (AFI) 36-2618, The Enlisted Force Structure, On-Line, Internet, 1.

⁴ Rod Hafemeister, "Raising the Standard—Updated AFI includes new courses and emphasizes teamwork." Air Force Times, On-line, Internet, 24 January 2005. available from <http://www.airforcetimes.com/print.php?f=0-AIRPAPER-598914.php>

⁵ AFI 36-2618.

Similar to their pilot counterparts, maintenance technicians first attend a formal education course in a particular specialty upon graduation from basic training. After graduating from this initial technical course, field-level training is provided within the major commands to provide additional instruction related to specific weapon systems and equipment technologies. Once junior airmen arrive at their respective field assignments on the flightline and in the maintenance shops, NCOs provide on-the-job training to and foundational experience for the professional growth of the young technicians.

Unlike their operations brethren, however, the maintenance community encounters significant challenges in sustaining professional development due to the lack of dedicated time afforded to the training of junior airmen. Whereas, a major part of the flying-hour budget is allotted to training new pilots, maintenance training is expected to occur concurrently with its support of operational (pilot) requirements. In a nutshell, wing resources are allotted for pilot training but rarely for exclusive maintenance training. While the relative differences in complexity of the two activities are debatable, any justification of the scheduled training inequity between pilots and maintainers fails to account for the necessity to establish a maintenance workforce balance to support future readiness requirements. This dilemma within the maintenance community often results in a continual shortage of qualified NCOs available to adequately support the daily flying mission. The negative by-product of these shortages is extended maintenance downtime for aircraft and longer work hours for line technicians. In addition to the negative effects on human capital, the wing also suffers diminished long-term sortie productivity due to maintenance training shortfalls.

In a 2002 policy letter, Gen John Jumper, Air Force chief of staff, designated aircraft maintenance a core competency of the US Air Force.⁶ The functions contributing to the maintenance of critical USAF aircraft resources include a web of flightline and shop activities which operate in concert to meet sortie requirements for training and contingencies. USAF wing-level maintenance functions consist of on-equipment activities which occur primarily on the flightline and include sortie-generation and aircraft-systems troubleshooting short of major component removal. Off-equipment

⁶ Scott Elliott, "Wings Undergo Major Reorganization." US Air Force Policy Letter, n.p. On-line. Internet, May 2002. available from <http://www.af.mil/policy/pdf/pl2002-05.pdf>.

maintenance activities include more intensive repair of aircraft systems and support equipment and usually involve the removal of major aircraft components and extensive downtime.

One critical off-equipment maintenance activity contributing to overall wing sortie production is performed by the maintenance flight of the Equipment Maintenance Squadron, commonly known as the *phase inspection section*. This hourly inspection is a consolidation of all lower-echelon inspection work packages and serves as a preventive measure to minimize aircraft downtime due to frequent scheduled and unscheduled maintenance requirements. The aircraft *phase flow* serves as the barometer to assess the sortie/flying hour potential of the wing's fleet and is closely monitored by flightline supervisors and senior wing leadership. Each weapon system, depending on Major Command (MAJCOM) established criteria, is assigned an hourly cycle for every phase inspection and prohibited from continued flying pending its completion. Consequently, the goal of flightline maintenance supervisors is to manage the expenditure of daily aircraft flight hours in order to squeeze the maximum sortie/hour potential of each assigned aircraft. Additionally, due to limited crew-chief and system-specialist manning, most wings have only one phase dock per squadron of 18-24 aircraft. This resource-limiting factor demands the management of aircraft hours using a time-distribution chart (TDI) to prevent more than one aircraft from *zeroing out* its hours at any one time.

The phase section's productivity is an important enabler for flying training and contingency requirements. It plays a key role in not only completing quality inspections in a timely fashion to maintain sortie productivity but also in identifying any aircraft discrepancies to mitigate maintenance downtime between inspection intervals. An efficient phase operation is the key to maximizing the wing's maintenance capability to support operational requirements.

Maintenance Metrics

Maintenance metrics, categorized as *leading* or *lagging* indicators, are applied to both fleet-availability and program-execution processes supporting wing flight operations.⁷ For fleet availability, leading indicators such as ground abort, air abort, and repeat/recur rates reflect the level of efficiency within the maintenance complex as it

⁷ "Maintenance Metrics—US Air Force," *Air Force Journal of Logistics*, 2001, 14.

supports the wing's flying mission.⁸ These leading indicators, in turn, cause fluctuations among the various lagging indicators which reflect overall maintenance effectiveness. The lagging indicators, via the mission-capable (MC) and non-mission capable (NMC) rates, are then used to depict historical trends which measure the wing's capability to meet training and warfighting requirements.

Whereas fleet availability metrics measure the resource viability of the wing's flying operation, program-execution metrics show the wing's capability to meet allocated flying-hour program requirements.⁹ The aircraft UTE rate is one of the most closely monitored of these program-execution metrics within the wing's aircraft-maintenance complex. A flying squadron's UTE is a key lagging indicator depicting the average number of sorties flown per assigned aircraft per month. The philosophy of UTE rate programming is not a new concept. The following 1981 Tactical Air Command Guidance outlines the seemingly timeless basic UTE concept:

The basics of the UTE rate system are simple. The unit is assigned an annual sortie UTE rate, the unit then specifies what Average Sortie Duration (ASD) it wants to fly, then the unit estimates how many aircraft it will have each month based known PDM [Programmed Depot Maintenance] inputs etc. A unit's flying hours are then allocated based on the product of their UTE rate times their ASD times the number of aircraft. Before getting into the actual steps in the development of a unit yearly program, we must make some assumptions. First, a unit may vary its monthly programmed UTE rate and average sortie duration any way it wishes provided that the year end UTE and average sortie duration meets the TAC year-end assigned goals. Secondly, the planning process, which varies the monthly UTE rate goals, is based on consideration for the number of O&M [Organizational and Maintenance] flying days in the month, historical weather and maintenance attrition, known exercises, PFT [Programmed Flying Training] loads (where applicable) and known PDM and mod[ification] schedules. And last is that the year end assigned UTE rate, if achieved, will produce enough sorties to satisfy aircrew requirements.¹⁰

Another factor contributing to the wing's ability to meet UTE goals is the size of the Primary Aerospace Vehicle Authorized, commonly known as the PAA.¹¹ The PAA

⁸ Ibid., 15.

⁹ Ibid., 17.

¹⁰ Tactical Air Command UTE Rate Programming & Information Guide, May 1981, 1-2.

¹¹ Air Force Instruction (AFI) 16-402, *Aerospace Vehicle Programming, Assignment, Distribution, Accounting, And Termination*, 1 August 1997, 2.

sets the baseline for the allocation of resources such as manpower, support equipment, and flying-hour funds. Another authorization category, the Backup Aircraft Vehicle Authorized Inventory (BAA) compensates for scheduled and unscheduled depot level maintenance, modifications, inspections, and other unexpected higher-headquarters maintenance and force-structure directives. A gap between PAA and the actual number of aircraft assigned to a wing (PAI) can create a strain on wing flying operations causing a heavier UTE burden on fewer aircraft. While this problem may not cause a degradation in readiness over the near term (many maintainers swear that the more an aircraft flies the less it breaks!), the long term stress on a low-PAI fleet can present significant challenges on the life-cycle sustainment of the aircraft weapon system.

A commonly misunderstood category within the aircraft authorization process is Attrition Reserve (AR) aircraft. These resources are procured for the purpose of replacing anticipated losses of PAA resources due to mishaps during peacetime or wartime attrition. Although intended as an overage to a wing's PAA, AR aircraft are often used to make up for aircraft shortages to meet programmed flying requirements. This remedy is often illusory, however, due to the fact that extra manning and resources do not accompany AR aircraft. A hypothetical scenario highlighting this problem is one in which a wing's fleet is scheduled for a short-notice extensive avionics modification. Although the per-aircraft maintenance time required to install the modification is expected to take seven work days, the flying schedule does not subside during the installation of the aircraft modification. In order to meet flying schedule commitments while facilitating the aircraft modification, the maintenance complex must rely on backup and attrition reserve aircraft to fill the aircraft resource shortage. This scenario is an example of how short-notice requirements and unexpected maintenance downtime can stretch the maintenance capability of the Air Force wing.

According to the *Metrics Handbook for Maintenance Leaders*, “the MC [Mission Capable] rate is perhaps the best known yardstick for measuring a unit's performance. This rate is very much a composite metric. That is, it is a broad indicator of many processes and metrics.”¹² MC rates come in three basic colors: FMC, PMC, and NMC. An aircraft reporting a FMC (Fully Mission Capable) status signifies that all mission

¹² “Maintenance Metrics—US Air Force,” *Air Force Journal of Logistics*, 2001, 37.

critical systems to the weapon system are *fully* functional. A PMC (Partially Mission Capable) aircraft usually has one or more mission critical systems inoperative despite the overall airworthiness of the aircraft. Lastly, an aircraft designated NMC is Non-Mission Capable and is either unable to meet any portion of its assigned mission or to safely operate as an airborne vehicle.

The MC rate serves as a gauge for wing leadership to determine whether enough aircraft are available to meet peacetime training and contingency requirements. Maintainers use the MC rate and its sub-metrics, TNMCM and TNMCS, to assess maintenance effectiveness and the overall health of the aircraft fleet. A high TNMCM rate can indicate training shortfalls which can hinder repair efforts on the flightline and in the shops. A high TNMCS rate highlights parts-supportability issues which could point to external inefficiencies at the air logistics centers (ALCs) or commercial parts vendors.

While these metrics offer a tremendous tool for maintenance and operations managers to assess training and combat capability, they alone do not provide the full solution to effective management of wing resources to meet higher headquarters requirements. Metrics provide roadmaps that enable maintenance supervisors and senior leaders to determine past performance, current challenges, and future potential. The notional bridge that links the ideals of data to definable results on the ramp is the *leadership* provided by flightline, backshop, and squadron-level supervisors who provide the daily tactical direction and guidance for the entire maintenance enterprise.

Modern-Day Challenges

In today's expeditionary Air Force, a continually high operations tempo poses significant challenges to aging weapon systems and deployment operations. Whereas Cold War tactical air operations featured steady-state training-oriented flying programs, current Global War on Terror (GWOT) operations demand continuous deployment cycles and split-squadron operations. An aging tactical air fleet pressed to fly expanding mission profiles compounds the readiness challenges of this new era.

Unfortunately, current MAJCOM-imposed flying-hour programs do not account for unscheduled contingency operations which create a tremendous burden on wing-level sortie production efforts. The evolution of the Expeditionary Air Force concept poses significant challenges to recurring pilot training and long-term aircraft sustainment.

Inevitably, this high operations tempo will decrease the projected life cycles of aircraft weapon systems, as tactical aircraft are continually subjected to higher stresses of aggressive training and combat flight maneuvers. The present dilemma facing the US Air Force is to confront steadily growing training and warfighting requirements with existing force-structure *or* to purchase more aircraft to meet sortie production demands.

Conclusion

A recent RAND study has indicated that as pilot training requirements increase to support modern expeditionary requirements, future capability to produce sorties must match these growing operational demands.¹³ While deliberations between Congressional appropriators and military leaders fuel the debate to determine production levels for the next-generation F-35 and F/A-22 tactical fighter/bombers, discussions with respect to sustainment are less spirited. Many Congressional leaders prefer to confront the inevitable sustainment bill when the effects of aircraft aging start to negatively impact readiness. This *I'll pay you later* philosophy places an unnecessary cost burden on annual DoD budgets and jeopardizes fleet-wide airworthiness. Early life-cycle planning, however, can mitigate these inevitable challenges and significantly reduce life-cycle sustainment costs. The F-16 sustainment crisis in the late 1990s is an example of how an inadequate life-cycle sustainment strategy can negatively affect aircraft readiness.

¹³ Dahlman, on-line, Internet, accessed 1 February 2005 available from <http://www.rand.org/publications/DB/DB382/>.

Chapter 2

The Fighting Falcon

... A few days later the Air Force made a last-ditch attempt to shoot down the lightweight fighter. A big part of [Secretary of Defense] Schlesinger's sales pitch for the lightweight fighter, one particularly convincing to congressmen, was that NATO countries were lining up to buy it. The Air Force moved to kill the international sales by saying the lightweight fighter was too limited in range to do anything but defend the home drome.

At last [Col John] Boyd announced the fuel fraction and range of the lightweight fighter. He added insult to injury by comparing it with the F-15. The lightweight fighter not only had greater range than the F-15, it had greater range than any fighter in the Air Force. Of course, foreign purchasing officials were euphoric, while Air Force generals reeled in shock ... Now there was nothing else the Air Force could do to stop the lightweight fighter ... The Fighter Mafia had won.

-Robert Coram

BOYD: the fighter pilot who changed the art of war

As the current workhorse of the tactical air forces, the F-16 has evolved into the world's premier dual-role-air-superiority/air-to-ground fighter aircraft. Over the past three decades, the Fighting Falcon has proven to be an important component of USAF airpower strategy and rendered exceptional performance in recent contingency operations. Throughout the life-span of the F-16 program, from its ground-breaking acquisition to its combat employment, the fighter has weathered the challenges of additional mission demands, high sortie utilization, numerous modifications, and structural deterioration. As the USAF's most employed fighter aircraft weapon system over the past 30 years, the F-16 offers a wealth of information regarding the effects of wing-level sortie utilization on the life-span of a tactical weapon system. Accordingly,

the lessons learned from the F-16 experience are relevant to the acquisition of the next-generation dual-role fighter, the F-35 Joint Strike Fighter. This chapter will analyze the history of the F-16 acquisition and assess USAF decisions regarding concept development, production, mission modifications, and employment in an effort to provide relevant context for future procurement efforts. Although the F-16 program matured in the political and technological context of the late-Twentieth century, its dynamic history offers a wealth of information for future planners, programmers, and warfighters for the Twenty-First century.

The Lightweight Fighter Program

In September 1971, the Prototype Program Office at Wright-Patterson AFB, Ohio initiated plans for the development of a lightweight fighter to test advanced aircraft technologies and reestablish the prototype development concept utilized by the Army Air Forces in the 1950s.¹⁴ The request for proposal (RFP) for this new fighter offered provisions for contractors to exercise considerable latitude and creativity to achieve the design goals stipulated by the Department of Defense (DoD). The initial guidance by the USAF Prototype Study Group issued the following design criteria:

Lightweight fighter prototype candidates should have a gross weight of less than 20,000 pounds; possess superior performance and maneuvering in the transonic, high-G regime; and be capable of operating in a 255 nautical mile (nm) combat radius on internal fuel, and 700 nm radius with external fuel. The aircraft should be capable of Mach 1 to 1.2 performance at sea level, and Mach 2 at altitude. It should be powered by engines already in the inventory or those in the last stages of development. Avionics for the lightweight fighter should be limited to mission essential; its armament should consist of a state-of-the-art cannon, and low cost but effective air-to-air missiles. The design should include hard points and associated systems for a credible air-to-ground capability; excellent pilot visibility; and excellent handling qualities.¹⁵

¹⁴ Clarence J. Geiger. "History of the F-16: Prototype to Air Combat Fighter, 1971-1975," Vol I Narrative. Air Force Systems Command, Wright-Patterson AFB, OH: ASD/HO, (June 1977): 5, in Deborah Gable. "Acquisition of the F-16 Fighting Falcon (1972-1980)" (Student Report 87-0900. Maxwell AFB, A.L.: Air Command and Staff College, 1987), 8.

¹⁵ Charles T. Janson and Kenneth C. Rogers, "Origins of the F-16 Multinational Program (1970-1977)," Vol. I, Narrative. Air Force Systems Command, Kirtland, AFB, N.M.: AFCMD/HO, (17 October 1983): 8-9, quoted in Deborah Gable. "Acquisition of the F-16 Fighting Falcon (1972-1980)" (Student Report 87-0900. Maxwell AFB, A.L.: Air Command and Staff College, 1987), 9.

This guidance provided the framework for source selection between the Northrop and General Dynamics corporations, each of whom set out to design, develop, and test a prototype candidate aircraft specified in the RFP.

Weapon System Development

During its development phase from 1976-78, the F-16 program encountered several challenges as engineers worked to evaluate weapon system components as well as determine production capabilities. During this period, engineers placed a great deal of emphasis on ensuring the viability of the aircraft radar, a critical part of the weapon system's combat capability. Additionally, due to the single-engine design of the F-16 aircraft, the reliability of the Pratt and Whitney F100-PW-100 engine became a critical factor in the viability of the program. As the development phase progressed, acquisition and requirement officials closely assessed the production readiness of contractors and subcontractors to determine future production capability and efficiency. Problems, ranging from the irregularities with the multimode pulsed Doppler radar, supplied by the Westinghouse Corporation, to a stall-stagnation anomaly with the Pratt and Whitney engine, garnered significant attention from USAF leaders charged with briefing the periodic status of the weapon system program to DoD and congressional leaders. Although the development contract provided funding based on a \$4.5-million-per-aircraft cost goal, each engineering and production setback threatened the overall program's progression to full-scale production.

Despite problems throughout and after the developmental phase with various aircraft components such as the radar, engine, and canopy; the F-16 program managed to stay afloat and continue progressing toward initial production and operational fielding. In May 1978, the system program office executed the initial production contract option for 105 aircraft as approved by the Defense Security Acquisition Review Council (DSARC) a year earlier. At a price of \$525.05 million, the F-16 had remained within cost, paving the way for a second order of 145 aircraft at \$484.93 million six months later.¹⁶ Subsequent reliability and maintainability tests proved successful for the first

¹⁶ -----, Small Wonder: "Development of the F-16 Fighting Falcon," 1975-1980. Vol. I, Narrative. Air Force Systems Command, Wright-Patterson AFB, OH: ASD/HO, (10 July 1986): 29, in Deborah

three production aircraft which posted a .83 hour mean-time-between-failure (MTBF) rate and an 83 percent mission reliability rate in compliance with the established initial operational capability (IOC) standards.¹⁷ In October 1980, the 4th Tactical Fighter Squadron assigned to Hill Air Force Base became the first F-16 unit to achieve IOC after successfully completing a Tactical Air Command Operational Readiness Inspection.

Evolution and Maturity

Throughout the F-16 production life-cycle, several system enhancements and structural modifications were developed to accommodate the changing requirements associated with the evolution of aircraft armament. Originally designed to meet a 6,000-hour design-life span based on primarily an *air-to-air* mission profile, the F-16 evolved into a multi-role weapon system in the mid-to-late 1980s. Through the Multinational Staged Improvement Program (MSIP), which began in 1980, the aircraft underwent three significant supplemental evolutions. In MSIP I, the F-16 received additional structural modifications and wiring to accommodate advanced avionics systems, increased stores, and higher “g” loading during combat maneuvers. The second MSIP stage, MSIP II, featured an upgraded cockpit, an additional advanced avionics suite, further structural beef-ups to carry the all-environmental, beyond-visual-range (BVR) Advanced Medium Range Air-to-Air Missile (AMRAAM), and the initial installment of the then-revolutionary precision-attack upgrade. MSIP III continued the avionics and software improvements by incorporating the Low Altitude Navigation and Targeting Infrared for Night (LANTIRN) system and reconnaissance upgrades which enabled real-time imagery via an advanced sensor pod.

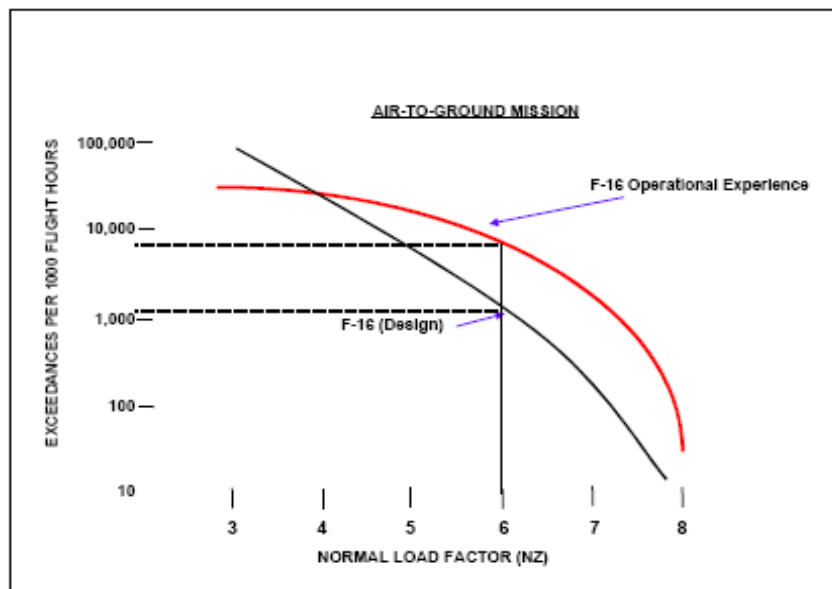
As the first fracture-based designed aircraft, the F-16 contained sub-structures capable of sustaining cracks imposed by rigorous flight regimes without failing catastrophically. Referred to as the weapon system’s damage tolerance life, this safety-of-flight metric served as an important planning factor in predicting the F-16’s projected life-cycle and force structure. Continuous reporting and monitoring of operational usage data via the Aircraft Structural Integrity Program (ASIP) “provid[ed] a basis for

Gable, “Acquisition of the F-16 Fighting Falcon (1972-1980)” (Student Report 87-0900. Maxwell AFB, A.L.: Air Command and Staff College, 1987), 33.

¹⁷ Deborah Gable, “Acquisition of the F-16 Fighting Falcon (1972-1980)” (Student Report 87-0900. Maxwell AFB, A.L.: Air Command and Staff College, 1987), 33.

improving structural criteria and methods of design, evaluation, and substantiation for future aircraft systems and modifications”¹⁸ This important data provided key insight during planning efforts to develop engineering inspection criteria for depot and field-level maintenance units.

The continuous evolution of tactics, training, and weapons has contributed to increased mission demands on the F-16 over the past three decades. Specifically, the cumulative effects of dual-role mission employment have caused stress loads up to ten times higher than the original design specification.¹⁹ The following chart depicts the operational stress placed on the F-16 by correlating the number of g-exceedences over 6Gs per 1000 flight hours. As reflected in the graphical comparison, F-16 operational usage has surpassed its intended design limits by a factor of 10, placing the airframe structure at risk for increased cracking beyond the damage-tolerance-life specifications. Moreover, the number of high-intensity g-exceedences per 1000 flight hours, determined by multiplying the gross weight of the aircraft by a standard normal load factor (NZ), reveal that operational and particularly air demonstration units have, over time, overstressed the aircraft up to four times the design limits. In reaction to this predicament, USAF engineers have attempted to recoup the diminishing life-span of the



¹⁸ Air Force Instruction (AFI) AFI 63-1001, *Aircraft Structural Integrity Program*, 18 April 2002, 2.

¹⁹ 1999 ASIP Analysis. Publisher unknown in Bryan Manes, “Extending USAF F-16 Force Structure” (Air Command and Staff College Research Paper, 2001), 16.

Figure 1: Typical Comparison: Design vs. Operational Usage²⁰

aircraft through the installation of upgrade modifications designed to reinforce vulnerable structural components. Since the late-1990s, these modification programs have played a significant role in stretching F-16 viability to the end its projected life-cycle.

Whereas other fighter weapon systems, such as the F-15, were subject to Programmed Depot Maintenance as a recurring inspection requirement, the F-16 design permitted field technicians to inspect and repair all of its components at base level. As such, when the weapon system began to face structural integrity problems, engineers proposed fleet-wide depot-level modification and repair programs to revitalize the health of the F-16 fleet. Falcon-UP, the first major modification effort, was performed by the Ogden Air Logistics Center for the purpose of reconstituting deteriorating aircraft sub-structures identified through the analysis of ASIP data and documented component failures in the field. Initial F-16 *blocks* (10/15) were exempted from this modification in an attempt to prioritize later models experiencing the brunt of the increased weight and tactical demands. In addition to Falcon-Up, the F-16 System Program Office initiated the Service Life Improvement Program, or SLIP, to repair damaged components and sub-structures on mid-production block 25/30/32 aircraft models.

Despite efforts of depot engineers to recover service life hours throughout the F-16 fleet, ASIP data collected from previously Falcon-up and SLIP modified aircraft revealed deterioration on high-fail potential components spurring the need for the most recent modification, Falcon-STAR.²¹ Priced at nearly \$1B, Falcon STAR targets high-fail potential components on blocks 25 through 52 with the goal of preserving the F-16's 8000-hour design service life projection.²² However, as the F-16 is increasingly tasked to deploy in support of real-world contingency operations at home and abroad, in addition to normal training requirements, the probability of continued airframe structural deterioration remains in the future. Heavy munitions loads, upgraded avionics suites, and increasingly aggressive tactical maneuvers work against any engineering effort to retard

²⁰ Tim Sorenson Engineer, F-16 System Program Office. "Falcon STAR briefing." F-16 SPO (12 Sep 1999): slide displayed in Bryan Manes, "Extending USAF F-16 Force Structure" (Air Command and Staff College Research Paper, 2001), 16.

²¹ *Air Force News* "Ogden Center Delivers First FALCON STAR F-16", February 10, 2004.

²² *Ibid.*

the inevitable effects of operationally employing an aircraft beyond its design limits. As the F-16 enters the twilight of its projected operational usefulness, its history and ongoing challenges highlight the ramifications of not properly addressing weapon system sustainment requirements.

Analysis of a Crisis

In retrospect, what could have been done to better assure initial F-16 service life projections? One school of thought holds that the deterioration of the fleet occurred as the result of an acquisition strategy that failed to keep pace with growing operational requirements. Another school, based on the history of previous fighter procurement efforts such as the F-4 and F-111, submits that the program is a victim of the absence of early sustainment requirements to compensate for the inevitable occurrence of *mission creep*. The logistician's perspective of the F-16 sustainment debate submits that the dwindling F-16 service-life occurred as a direct result of not integrating reliability and maintainability into design of the aircraft. Although the ASIP program was instituted as a diagnostic tool to alert maintenance technicians and engineers of impending F-16 structural component failures, the USAF's inability to provide funding to conduct proper analysis of structural data prior to 1999, crippled the program's ability detect excessive damage to critical sub-structures.²³

Currently, the F-16 comprises 50 percent of the USAF tactical fighter force structure. During Operation Iraqi Freedom, of the 293 USAF fighters employed by Central Command Air Forces (CENTAF), 131 or 52 percent were F-16s.²⁴ Moreover, the F-16s flown by the Air National Guard and AF Reserve components shoulder the lion's share of Operation Noble Eagle contingency requirements. Recent Headquarter US Air Force aircraft statistics reveal that the current fleet is posting mission capable rates at 75-79 percent compared to the ACC MAJCOM imposed standard of 83 percent.²⁵ This decline in mission capability, juxtaposed with the significant reduction in fighter force structure during the 1990s, exacerbates the mission stresses on the F-16 weapon system.

²³ Bryan Manes, "Extending USAF F-16 Force Structure" (Air Command and Staff College Research Paper, 2001), 18.

²⁴ Lt Gen T. Michael Moseley, CENTAF Commander, *Operation IRAQI FREEDOM—By the Numbers*, CENTAF Assessment and Analysis Division, 30 April 2003, 9.

²⁵ USAF/IL. *Merlin Aircraft Metrics Database*. Accessed 12 June 2005.

From a force-structure-management perspective, the USAF strives to maintain tactical aircraft fleets at an average age of 11 years with a corresponding goal to retire current fighters with 22 years of service.²⁶ Today's force-structure challenges together with constant contingency operational requirements present several dilemmas for USAF leaders attempting to nurse the existing F-16 fleet while fighting to field the next-generation JSF. Considering that fighter flightline and programmed depot maintenance requirements historically skyrocket after 15 years of service, the projected investment needed to sustain the F-16 will become cost-prohibitive by the year 2020. Moreover, the ongoing acquisition of the F-35 Joint Strike Fighter will not fill the force-structure gap left by impending aircraft retirements in the 2015-2020 timeframe. In an effort to remedy this dilemma, HQ/USAF considered an unconventional approach to preserve early-model F-16s in storage to meet possible shortfalls caused by delayed fielding of the JSF.

The aircraft set-aside proposition in the 1996 Program Decision Memorandum (PDM) for the 1998 Budget Estimate Submission (BES) submitted to the Deputy Secretary of Defense offered the following solution to the projected fighter gap in the second decade of the Twenty-First century:

The Secretary of the Air Force will reserve in inviolate storage for potential future [US] use the following F-16A/B Block 15 aircraft: Immediately, 100 good condition aircraft; in the year 2000; in addition, 100 aircraft received from the Air Force Reserve and Air National Guard. The need for maintaining this secure storage program will be reviewed one year prior to commencement of long lead procurement for low-rate initial production of Joint Strike Fighter.²⁷

Measures such as the one described above signify a desperate, inefficient, and reactionary attempt to fix a problem using a temporary *band-aid* approach. It further highlights the need for a collective synergy between maintenance, supply, and engineering support functions to assure an aircraft's life-cycle viability. As the USAF constructs Future Years Defense Plans (FYDP) over the next decades, the expedited procurement of the F-35 (JSF) weapon system is one option being considered to reduce the fighter force-

²⁶ "USAF Almanac 2004: The Air Force Facts and Figures," Air Force Magazine On Line, Internet, May 2004, 58-60.

²⁷ Deputy Secretary of Defense, Program Decision Memorandum, subject: Tactical Aircraft Modernization, (14 August 1996), quoted in Brian Manes, "Extending USAF F-16 Force Structure" (Air Command and Staff College Research Paper, 2001), 25.

structure gap and maintain US tactical aviation superiority. However, unless the JSF procurement strategy features an *integrated* life-cycle procurement *and* sustainment approach, it too will fail to fulfill service-life projections and exacerbate existing force structure shortages.

Conclusion

The acquisition of a major weapon system involves many divergent forces forcing senior leaders to make tough decisions in a hotly contested budgetary environment. Although just one aspect of the larger process shaping the complexion of a procurement effort, the meshing of operational and logistics goals often takes a back seat to more contentious political budgetary issues regarding aircraft unit-fly-away costs. As the USAF determines the procurement phasing for the F-35, considerations of base-level logistics infrastructure as well as life-cycle sortie capacity should occur throughout the planning process in an effort close the gap on the dichotomy of mission efficiency vs. mission effectiveness.

Chapter 3

The F-16: Adaptation of Logistics to Change

"There is nothing more common than to find considerations of supply affecting the strategic lines of a campaign and a war."

- Carl von Clausewitz

"My logisticians are a humorless lot ... they know if my campaign fails, they are the first ones I will slay."

- Alexander

"I don't know what the hell this 'logistics' is that Marshall is always talking about, but I want some of it."

- Fleet ADM E. J. King: To a staff officer (1942)

Total life-cycle costs associated with military weapon systems generally fall within two areas: procurement and sustainment. The procurement costs of major weapon systems often receive a great deal of attention during the vetting of DoD priorities each fiscal year. However, sustainment costs often take a backseat to current-year priorities and do not surface until a particular weapon system begins to suffer the effects of material deterioration. The military services typically face tough Congressional scrutiny when submitting funding requests for the design, testing, and production of new and unproven weapons technologies. As a result of this scrutiny, the service departments settle for smaller production increments during early procurement phases. However, once developmental technologies are proven, robust production runs become more politically viable. The rate and method of acquisition greatly affects the corresponding development and supportability of the weapon system's initial sustainment infrastructure

as well as subsequent modifications. Furthermore, the successful long-term mission readiness of the weapon system directly correlates with the validity of logistics decisions made during the first two years of its life cycle. A study of the interactions between logistics and operations factors early in an acquisitions program provides one way to determine future life-cycle requirements. The development of the F-16 sustainment infrastructure offers a perspective on how this process occurs.

In the late 1970s and early 1980s, two separate USAF major commands, Air Force Systems Command (AFSC) and Air Force Logistics Command (AFLC) managed the requirements generation process for the F-16 weapon system.²⁸ In addition to facilitating relationships with the numerous prime and subcontractor firms for the weapon system, AFSC and AFLC formulated production requirements forecasts for F-16 life-cycle sustainment. Critical to the sustainment effort was the forecasting process that informed contractors of replacement-component and spare-parts requirements.²⁹ Better reliability of F-16 sub-components, resulted increased mean-time-between failure rates for this new weapon system. But the same technology and complexity also extended the production time associated with delivering key spares--often produced by a single vendor.³⁰ The ability to minimize dependency on long lead times for spares production was vital to assure aircraft readiness. Consequently, readiness posture planning rested on an early procurement choice: either purchase a greater number of weapon system units to attain a desired mission capable rate through efficient utilization or invest in an adequate sustainment infrastructure to support a smaller fleet of aircraft subject to higher aircraft utilization over time.

Logistics requirement forecasting is a key part of any procurement process and serves as a barometer for predicting weapon system service life. Two types of forecasting models exist for predicting future demand of replacement components and spare parts. The use of historical trends as a predictor of future demand is one modeling approach while another model focuses on assessing the technological evolutions which could affect weapon system performance and effectiveness. An example of the latter

²⁸ Charles M. Reynolds and Richard D. Schikora, "An analysis of the F-16 Aircraft Requirements Generation Process and its Adverse Impact on Contract Rate Capacity," Air Force Institute of Technology, September 1982, 1.

²⁹ Ibid., 2.

³⁰ Ibid., 2.

approach is the procurement of the C-17 airlifter which considered sustainment issues associated with the requirement to take-off and land in austere airfield environments.

The economic laws of supply and demand apply to weapon system procurements as they do to domestic goods and services. Manufacturers prefer accurate customer requirements forecasts in order to plan efficient production runs for specified items. On the other hand, short-notice demands based on unforeseen requirements create significant challenges to manufacturers, who must achieve production goals based on effectiveness, as opposed to efficiency. Reactive production results in higher costs to the government by limiting manufacturer flexibility to improve production over the weapon system's life cycle. Additionally, reactive planning creates higher labor costs for contractors who must resort to inefficient hiring practices in order to meet temporary production surges.³¹ In order to mitigate these limiting factors, a consolidated approach to setting demand levels is preferred to optimize customer flexibility and supplier profit margin stability.

The benefits of consolidated demand forecasting apply equally to the procurement of spare parts, subsystem components, and initial weapon-system buys.³² The advantages of increased price competition as well as a reduced production costs entice potential manufacturers to bid on larger guaranteed contracts and create a win-win scenario for both sides of the transaction. As discovered with the F-16 Multiyear Contract instituted in 1982, which featured a consolidated demand forecasting approach, large production runs incentivized vendors to reduce manufacturing costs to increase profits.³³ Furthermore, the larger volume enabled contractors to offer savings to customers due to the predictability of a guaranteed flow of production orders. The incorporation of consolidated forecasting into the procurement process is a key enabler to ensuring weapon system life-cycle sustainability while minimizing contract and vendor costs.

A Decade of Readiness Challenges

The deterioration of F-16 aircraft readiness throughout the 1990s was a function of overall trends in two negatively correlated maintenance indicator metrics: gradually declining MC rates compounded with a steadily increasing Non-Mission Capable (both

³¹ Ibid., 3.

³² Ibid., 3.

³³ United States General Accounting Office, Report to the Chairman, Subcommittee on Defense, Committee on Appropriations, House of Representatives: Procurement, An Assessment of the Air Force's F-16 Aircraft Multiyear Contract (Washington D.C.: GAO, 1986) 6.

Total Non-Mission Capable due to Supply and Maintenance) rates.³⁴ The capability to accurately forecast requirements with respect to both maintenance and supply disciplines is key to determining the resources (budgetary and equipment) needed to achieve desired mission readiness levels. Central to this forecasting capability is the understanding of the interrelatedness of the variables (MC, TNMCM, TNMCS) affecting maintenance capability. An analysis of these two key metrics, TNMCM and TNMCS, sheds some light on possible root causes associated with the increasing negative logistics indicators during this period.

In the year 2000, Air Force Chief of Staff Michael Ryan asked his Deputy Chief of Staff of Installations and Logistics, “What are the main causes for increasing TNMCM rates over the last few years?”³⁵ An answer to the CSAF’s question is found in a 2000 study conducted by the Dynamics Research Corporation (DRC) for the HQ USAF Directorate of Supply. DRC grouped NMCM causal factors into two categories, reliability/maintainability (R&M) and personnel retention.³⁶

A weapon system’s R&M is a key component to mission readiness and influences trends in TNMCM rates. R&M is determined by assessing total aircraft operating time as well as factoring changes in environmental conditions which extend the aircraft beyond its originally projected flight operating envelope. When these variables are high, due the severe stresses caused by operations beyond aircraft design limits, the overall reliability of components and major aircraft structures decrease. Furthermore, the weapon system’s maintainability, reflected in the TNMCM rate as a function of cumulative repair time, is also negatively affected by the excessive operational wear-and-tear. A 25 April 2005 article in Air Force Times summarizes the recent fatigue issues associated with the F-16:

Airframe fatigue concerns with the F-16 Fighting Falcon account for half of the (USAF) aircraft officially on restriction. The Air Force counts 1,294 of its 1,341 F-16s as needing airframe reinforcements if the plane is

³⁴ Steven A. Oliver, Alan W. Johnson, Edward D. White, and Marvin A. Arostegui, “Forecasting Readiness,” *Air Force Journal of Logistics*, Summer 2001, 1.

³⁵ Russell P. Hall. HQ USAF/IL, Total Not Mission Capable for Maintenance Project Description Memorandum, 5 Jan 00, quoted in Steven A. Oliver, Alan W. Johnson, Edward D. White, and Marvin A. Arostegui, “Forecasting Readiness,” *Air Force Journal of Logistics*, Summer 2001, 1.

³⁶ Mark Humphrey, “NMCM Escalation and Erosion of Mission Capable Rates,” DRC Contract #GS-35F-477SG, Sep 99 and John E. Bell, “Total Not Mission Capable for Maintenance Study,” AFLMA Project #LM199934800, Oct 00 in Steven A. Oliver, Alan W. Johnson, Edward D. White, and Marvin A. Arostegui, “Forecasting Readiness,” *Air Force Journal of Logistics*, Summer 2001, 31.

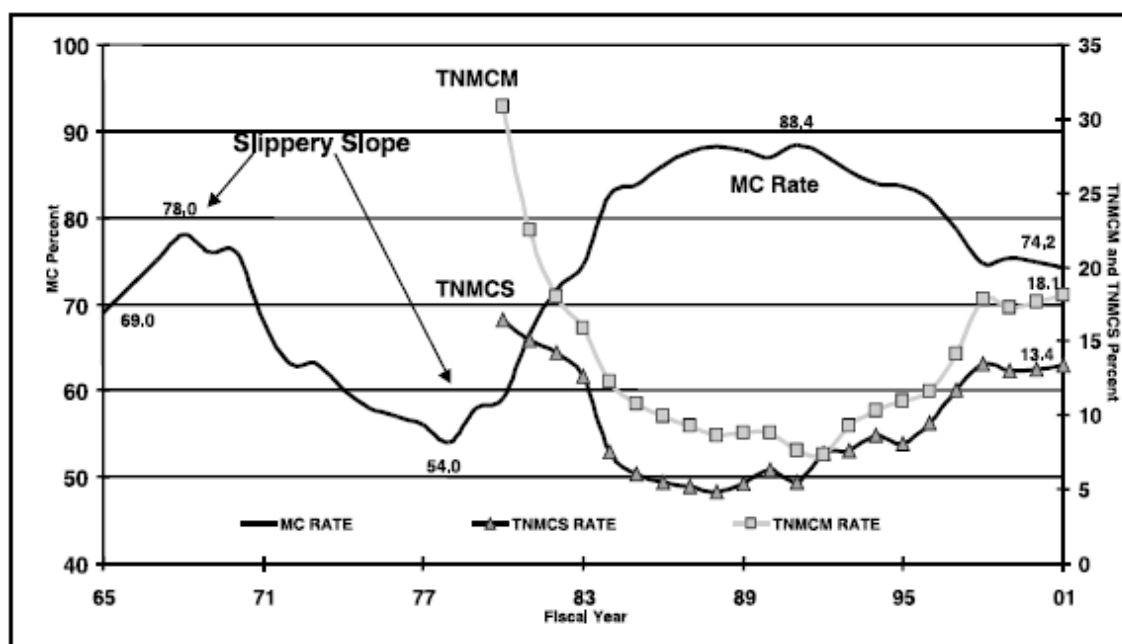


Figure 2: MC Rates for Fighter Aircraft (MC, TNMCM and TNMCS Rate Changes, 1965-2001)³⁷

to reach 8,000-plus hours in the sky ... [t]he problem isn't a single broken part, but the general wear and tear on the jet's fuselage ... [w]hen the F-16 started coming off production lines in the 1980s, the Air Force thought it would fly each jet for about 4,000 hours and then retire it. Now, the Air Force wants each jet to reach more than 8,000 hours.³⁸

According to Colonel Mike Vidal, Commander of the 508th Fighter Sustainment Group at Ogden AFB, UT, the USAF will strengthen the F-16 airframes through the Falcon Structural Augmentation Roadmap (Falcon STAR).³⁹ The Falcon Star program utilizes part kits valued at nearly \$1 billion to reinforce deteriorating major aircraft structures and smaller components subjected to operational over-use and general aging.⁴⁰

The effects of excessive operational usage may not necessarily manifest themselves in daily metrics, such as MC rates and break rates, which are used to measure aircraft readiness and maintenance effectiveness.⁴¹ During the 1990s, for instance, increased operational usage only slightly increased aircraft break rates (a measurement of

³⁷ Ibid., 31

³⁸ Bruce Rolfsen, "On Lockdown," *Air Force Times*, April 25, 2005, 15.

³⁹ Ibid.

⁴⁰ Ibid.

⁴¹ Oliver et al., 30-32.

the number of pilot-reported discrepancies caused by a maintenance condition).⁴² According to a 2000 AFLMA TNMCM study, however, the number of discrepancies discovered during phase maintenance inspections increased 174% from 1995 to 1999—a period where the F-16 was employed at high rates due to contingencies in European and Middle East theaters.⁴³ This drastic increase in phase-discovered discrepancies reduced the productivity of unit-level aircraft phase sections and subsequently degraded overall sortie capacity. The R&M downward spiral was further compounded by the increase of MAJCOM/SPO-directed TCTOs and Special Inspections to repair unforeseen structural and component malfunctions caused by aging and overuse.⁴⁴ The highly technical modifications and inspections further drained already-depleted manpower resources and add to increasing TNMCM rates.

TNMCS rates are also influenced by quantifiable and non-quantifiable factors which negatively correlate to the overall weapon-system MC rate.⁴⁵ Factors such as subsystem reliability and demand, the level and mix of serviceable inventory, and component repair times are all measurable and can provide input to an overarching TNMCS metric.⁴⁶ Other factors, such as phased-out manufacturing sources, materiel shortages, and inventory forecasts are not as measurable and require further investigation in order to determine causal relationships to overall TNMCS trends.⁴⁷ Occasionally, both TNMCS and TNMCM rates reflect influences by the same external factors that often indicate inefficiencies in the larger repair cycle. The cause-and-effect relationships between component reliability, demand rates, available inventory, and maintenance practices combine to determine repair cycle health, which is integral to the wing's maintenance capability.

Depot repair time is another causal factor in the determination of weapon system TNMCS rates. The significance of the depot infrastructure to aircraft readiness became readily apparent in the early-to-mid 1990s when the closing of 40% of the USAF's total

⁴² Ibid

⁴³ John E. Bell, "Total Not Mission Capable for Maintenance Study," AFLMA Project #LM199934800, Oct 00, quoted in Steven A. Oliver, Alan W. Johnson, Edward D. White, and Marvin A. Arostegui, "Forecasting Readiness," *Air Force Journal of Logistics*, Summer 2001, 32.

⁴⁴ Ibid., 33.

⁴⁵ Ibid.

⁴⁶ Ibid.

⁴⁷ Ibid

air logistics center (depot) infrastructure placed an inordinate strain on the repair cycle.⁴⁸ Former Secretary of the Air Force Whitten Peters highlighted these effects in 2000 in the following statement to an Air Force Association gathering:

Directly relevant to readiness were the closures of two of the five Air Force maintenance depots ... almost immediately upon announcement, these closures created turmoil at our depots as skilled workers started to leave the closing depots well in advance of the actual closure dates. The most serious aircraft readiness problems ... were caused by our inability to move production lines on schedule and ... our inability to hire skilled manpower at the receiving depots ... we are still hundreds of people short at two of our depots.⁴⁹

Two-Level Maintenance

In the midst of this dwindling infrastructure, the USAF also decided to streamline the maintenance repair management process via the *two-level maintenance* (TLM) concept. For the F-16 in particular, this initiative essentially eliminated the base-level maintenance capability for a range of aircraft components and transferred the responsibility to the remaining air logistics centers.⁵⁰ TLM, in theory, was conceived to reduce the size of the USAF logistics infrastructure by eliminating redundancies between base and depot-level repair activities.⁵¹ Furthermore, the TLM concept strove to reduce robust mobility requirements required to sustain contingency operations.⁵² The TLM initiative's *carrot* was the prospect of significant capital equipment and manpower savings while reducing force protection requirements during deployments.⁵³

Whereas the TLM initiative succeeded in achieving its footprint-reduction and cost savings goals by recouping \$259M in capital expenditures and eliminating 4,430 manpower positions, it created additional expenses due to inefficiencies created in the new streamlined repair cycle.⁵⁴ Both TNMCM and TNMCS rates, for the F-16, suffered

⁴⁸ Ibid.

⁴⁹ F. Whitten Peters, "Readiness Challenges of Today's Air Force," Remarks to the Air Force Association National Convention, Washington DC, 13 Sep 00, quoted in Steven A. Oliver, Alan W. Johnson, Edward D. White, and Marvin A. Arostegui, "Forecasting Readiness," *Air Force Journal of Logistics*, Summer 2001, 33.

⁵⁰ Oliver, 35.

⁵¹ Ibid.

⁵² William J. Ames, "Logistical Effectiveness of Two-Level Maintenance" (research report submitted to the Air Command and Staff College faculty, April 2000), 6-11

⁵³ Ibid.

⁵⁴ Oliver, 33

under TLM as thousands of repair parts created a bottleneck in a transportation system unable to keep up with demands for base-level maintenance repair requirements. As a result of TLM's inability to fill the gap left by the intermediate repair shops, flightline technicians began to *cannibalize* desperately needed parts from non-scheduled aircraft to meet scheduled operational requirements and unscheduled contingencies. The parts-cannibalization process, while a viable alternative in some cases, created an additional maintenance workload and increased the probability of causing damage to a part during the removal process. Although many factors, such as fewer spare parts and aging aircraft systems, can contribute to high cannibalization rates within a maintenance unit, an inefficient off-equipment maintenance repair and transportation system drastically increases the instability of the repair cycle. Although not the sole culprit, TLM inefficiency was one, if not the most significant, cause of the 78% increase in aircraft cannibalizations during the 1990s.⁵⁵ In the final analysis, TLM exposed the disparate priorities of operationally-focused flightline organizations and business-minded wholesale logisticians. Whereas aircraft mission-capability remained the most important priority to the flying and maintenance units, the depots strove to achieve cost reductions by "delay[ing] repair activities until enough parts accumulated so it was cost-effective to repair them ..."⁵⁶ In the end TLM proved to be a one-sided solution to a multi-dimensional problem and failed to deliver its most basic promise of budget relief.

The effects of these drawdown actions furthered the deterioration of the post-cold-war USAF sustainment infrastructure and ultimately created a readiness crisis which continues to exist as of the writing of this paper. Constrained defense budgets compounded by a new and dynamic operational environment during the 1990s contributed to the spiraling of USAF fleet health to unconscionable depths. Absent significant funding supplements to rebuild the aircraft sustainment infrastructure, the attempts to reverse increasing TNMCS and TCM rates during the 1990s yielded temporary results and at best, merely addressed the minor symptoms of a debilitating disease.

⁵⁵ Mark Humphrey, "NMCM Escalation and Erosion of Mission Capable Rates," DRC Contract #GS-35F-477SG, Sep 99, quoted in Steven A. Oliver, Alan W. Johnson, Edward D. White, and Marvin A. Arostegui, "Forecasting Readiness," *Air Force Journal of Logistics*, Summer 2001, 35.

⁵⁶ *Ibid.*

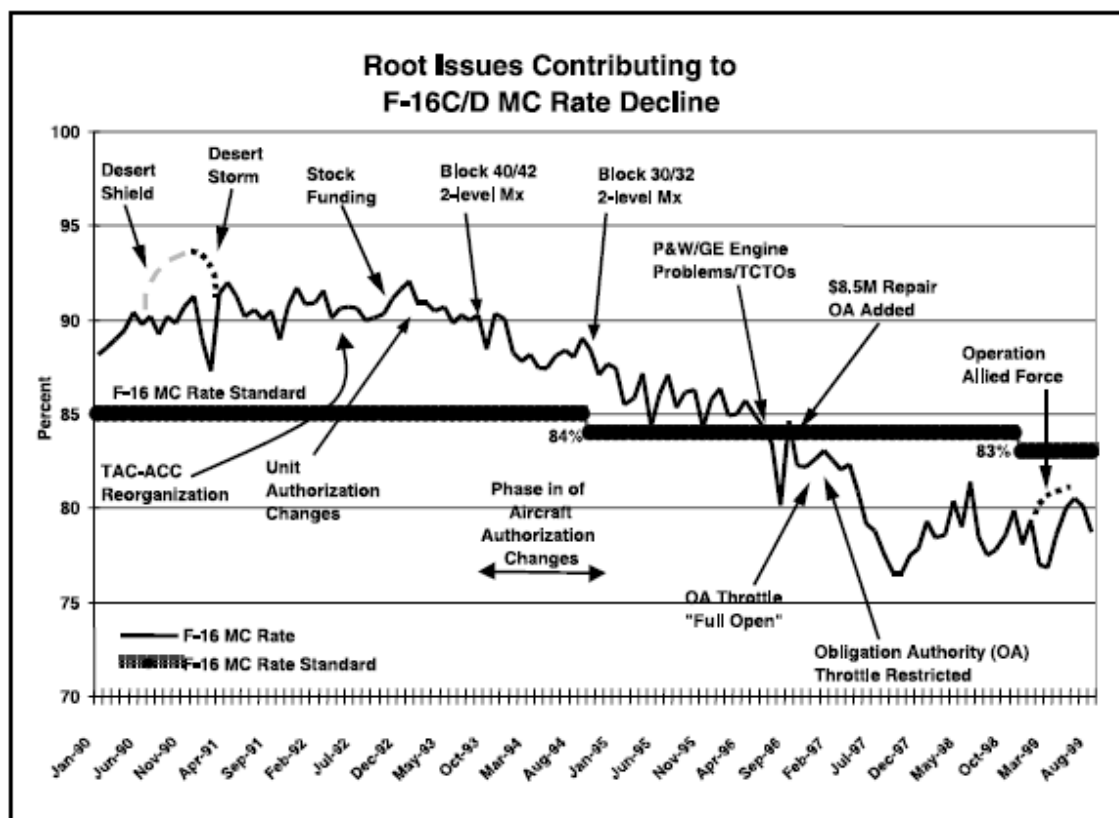


Figure 3: F-16C/D MC Rates, 1990-1999⁵⁷

Personnel Shortages

As stated in Chapter 1, the quality of trained maintenance personnel is critical to sustaining aircraft readiness. Quantifiable factors which measure the capability of the maintenance personnel force include the enlisted manning levels in two air force career fields, 2AXXX and 2WXXX, which directly support sortie generation on the flightline.⁵⁸ In addition to the raw numbers of personnel in these critical line support career fields, specific personnel experience levels also factor into the assessment of overall maintenance capability. The ratio between Airman trainees, fresh out of technical school, to veteran NCO technicians is a key indicator to the health of the wing maintenance

⁵⁷ Charlie Krueger, Lockheed Martin Tactical Aircraft Systems, Fort Worth Texas, 1999 in Steven A. Oliver, Alan W. Johnson, Edward D. White, and Marvin A. Arostegui, "Forecasting Readiness," *Air Force Journal of Logistics*, Summer 2001, 35.

⁵⁸ Dahlman and Thaler; Humphrey; and Leonard R. Gauthier, 1st Fighter Wing Aircraft Abort Study, 1 OSS/OSMA, ACC, 1998, in Steven A. Oliver, Alan W. Johnson, Edward D. White, and Marvin A. Arostegui, "Forecasting Readiness," *Air Force Journal of Logistics*, Summer 2001, 31.

complex.⁵⁹ If this ratio is large, trends in hourly fix rates, code 3 breaks (major subsystem malfunctions), and overall mission-reliability suffer. Furthermore, the same correlation exists with respect to the average total years of military service within the enlisted maintenance force.⁶⁰ Technicians with more than four years experience represent an important demographic for the maintenance-career-field managers who monitor retention rates and future force management. These technicians not only provide key leadership and expertise within maintenance units but also perform the important task of training the next generations of maintenance journeymen. Therefore, during the 1990s when retention rates dropped significantly as result of a vibrant civilian economy, maintenance capability suffered as the training pipeline struggled to replace highly-trained and experienced technicians.

The positive relationship between retention and readiness also serves as an accurate predictor of NMCM rate trends. Throughout the 1990s as the military forces shrunk, the maintenance force became inexperienced and task-saturated amid training shortfalls, causing NMCM rates to rise. In his testimony to Congress in 1999, General Richard E. Hawley, Commander, Air Combat Command addressed the ills of a military personnel drawdown compounded with an inability to retain experienced personnel:

We have a very low-experienced force ... particularly in Air Combat Command because the forward deployed get priority in personnel and parts ... lower retention means a shortage of five-level maintenance personnel, the journeymen technicians who should constitute the bulk of the workforce. That means too much of the maintenance work is being done by younger three-level personnel, who require more supervision and take longer to do a job.⁶¹ We have a very low-experienced force ... particularly in Air Combat Command because the forward deployed get priority in personnel and parts ... lower retention means a shortage of five-level maintenance personnel, the journeymen technicians who should constitute the bulk of the workforce. That means too much of the maintenance work is being done by younger three-level personnel, who require more supervision and take longer to do a job.⁶²

⁵⁹ Ibid.

⁶⁰ Ibid.

⁶¹ Otto Kreicher, "Hawley's Warning," *Air Force Magazine*, July 1999, 52.

⁶² Ibid., 55.

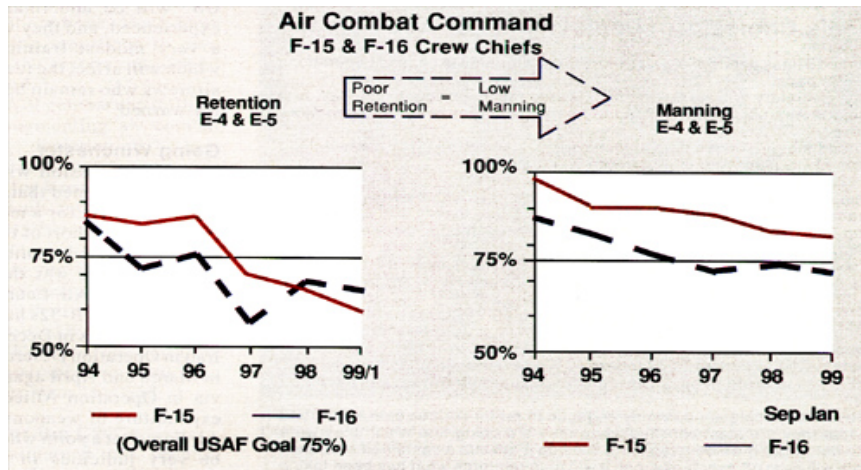


FIGURE 4

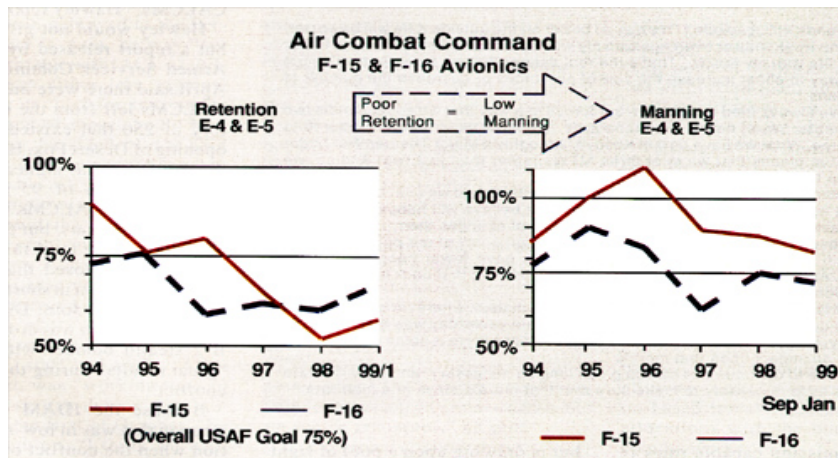


FIGURE 5

These retention issues posed significant challenges to the logistics community in that inexperienced personnel shouldered the readiness burden in a dynamic operational environment. During the 1990s, many senior maintenance leaders were forced to trade mission capability effectiveness for training efficiency in order to rebuild an experienced cadre of line technicians. When correlating Figures 4 and 5 with Figure 2 shown earlier, the retention rates for F-16 crew chiefs and avionics technicians suffered concurrently with decreasing MC rates during the mid-1990s.⁶³ This highlights the importance of adequate training, high morale, and equipment R&M to overall mission readiness.

⁶³ Figures 4 and 5 found in Otto Kreicher, "Hawley's Warning," *Air Force Magazine*, July 1999, 52-55.

Different Geopolitical Context – Same Infrastructure

The post-cold war 1990s era presented a series of geo-political and socio-economic circumstances resulting in the redistribution of budget priorities created by the *peace dividend*. Previously robust USAF budgets which eclipsed \$120.0B during the mid-1980s began to rapidly drop after the fall of the Berlin Wall in 1989.⁶⁴ Although the end of the cold-war radically changed the national and international security environment, costs to maintain existing infrastructure and sustainment levels did not disappear with the changing political context. Mid-1990s funding for aircraft sustainment, however, ignored this fact and suffered reductions by up to 42 percent.⁶⁵ Specifically, a Dynamics Research Corporation study reported that in FY95 and FY 96, spare-parts funding fell to 58 and 74 percent of requirements.⁶⁶ The study also concluded the correlation between sustainment funding and MC rates was sensitive to even the slightest under-funding of projected readiness requirements.⁶⁷ In addition to the Operations and Maintenance (O&M) spending reductions, increased operations/personnel tempos and management streamlining also posed significant threats to USAF force structure and overall mission readiness.

High Ops-Tempo

Due to the fiscally-strained context of the post-cold war era, routinely high OPSTEMPO and PERSTEMPO rates became a normal way of doing business for USAF operations and maintenance units. The high number of deployments associated with post –cold war contingency operations, combined with a significant personnel drawdown, produced an organizational culture of *doing a great deal more with less*. In a 1998 statement during a congressional hearing conducted by the House National Security Committee, Senior Master Sergeant David Rodriguez explained the dilemma faced by aircraft maintainers in their daily attempts to preserve mission readiness in a high-ops tempo environment despite dwindling resources:

⁶⁴ Oliver, 34.

⁶⁵ Mark Humphrey, “NMCM Escalation and Erosion of Mission Capable Rates,” DRC Contract #GS-35F-477SG, Sep 99 and Andy Sherbo, “Operations and Maintenance Funding and the Art of Readiness.” The Air Force Comptroller, Apr 98, 32, 10-14 in Steven A. Oliver, Alan W. Johnson, Edward D. White, and Marvin A. Arostegui, “Forecasting Readiness,” *Air Force Journal of Logistics*, Summer 2001, 34.

⁶⁶ Ibid.

⁶⁷ Ibid.

Operations tempo has greatly impacted the way we accomplish maintenance. We have to accomplish more maintenance in less time. Prior to every deployment to Southwest Asia (SWA), we spend a minimum of four months preparing the aircraft for the deployment. We start by looking at the records of our own aircraft to see if the scheduled "Time Change" items, Time Compliance Technical Orders, and scheduled depot modification will allow the aircraft to deploy. These items must have ample time remaining for the aircraft to deploy and return to home station without grounding the aircraft. We do not accomplish these types of inspections in SWA because the aircraft will not be available [from] the flying schedule. Also, if a part is required and not available, the aircraft could be unusable for weeks while the part makes it in country. If we have an aircraft where these items cannot be completed before deploying, we swap the aircraft with one from another squadron. Once the deploying aircraft is in the squadron, we begin to accomplish these items as well as scheduled and preventative maintenance. This usually means removing the aircraft from the flying schedule for a week in order to accomplish just one of the following: paints, boresights, annual gun inspections, landing gear, Time Compliance Technical Orders, and delayed discrepancies. If the aircraft requires more than one of these inspections to be accomplished then more down time is scheduled. When deployments or vulnerability windows to deploy to SWA are six months apart, as they currently are, we have to accomplish a year's worth of maintenance in just eight months, or less if you have other deployments.

Between SWA deployments, there are usually one or two other deployments or local Operational Readiness Exercises. During the deployments we continue to fly home station sorties. This requires a delicate balancing act between the pilots requiring the remaining home station aircraft for training and the maintainers needing them for maintenance and for training. The remaining work force and experience level also diminishes, because you are now split between home and deployed locations. During Operational Readiness Exercises, all aircraft are made available for the flying schedule. This results in the SWA aircraft maintenance preparation coming to a complete halt. So, instead of having eight months to complete a year's worth of maintenance, you now have about six to seven months to complete it all. The increase in sorties required for pilots to remain mission ready has also impacted maintenance. In the past, we could launch just two launch windows in order to meet their requirement. Now we have to launch three missions in order to meet this new requirement and during one week out of the month we launch a fourth set of missions. This minimizes the amount of time we have to repair aircraft between missions. This in-turn causes us to use our 7-levels to fix problems as quickly as possible, and valuable experience for our 5-levels and training opportunity for the 3-levels is lost. We are asking for more and more from our personnel but we are not supplying

them with the parts, equipment and the time necessary to gain experience needed to do their jobs.

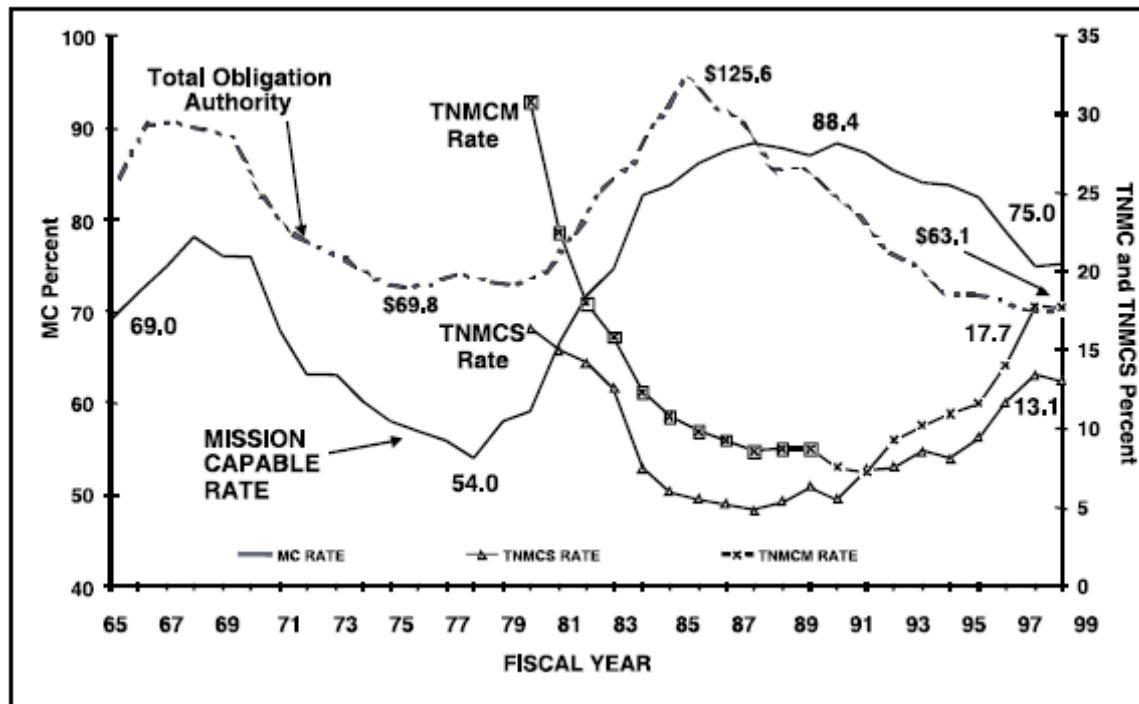


Figure 6: Total Obligation Authority Versus MC Rates, 1965-1999⁶⁸

We do not have the personnel available to give that quality one-on-one training so desperately needed to ensure a well-trained and experienced Air Force of the future. As I've described, our aircraft fully mission capable rate in the last five years has changed from 92.5 percent to 76.5 percent. I believe if we had to deploy two squadrons at the same time we would not have enough aircraft, equipment, or experienced personnel left behind for the remaining squadron to conduct normal training operations.⁶⁹

Senior Master Sergeant Rodriguez's perspective from the field not only describes the stresses of a post-cold war operating environment but also highlights the essentiality of preserving adequate weapon system sustainment levels (parts and equipment) to mitigate the unpredictable challenges associated with meeting readiness goals. Among the major

⁶⁸ Stanley Sieg, AFMC/LG, "Improving Customer Support Through Supply Chain Management and Constraints Analysis," Briefing, 16 Jun 00 slide displayed in Steven A. Oliver, Alan W. Johnson, Edward D. White, and Marvin A. Arostegui, "Forecasting Readiness," *Air Force Journal of Logistics*, Summer 2001, 34.

⁶⁹ House, Statement prepared for House National Security Committee Readiness Hearings, 1st sess., 1998.

factors contributing to mission readiness, reduced weapon system sustainment funding (spare parts, depots, infrastructure) can create dire circumstances for service-life viability.

Conclusion

The procurement and sustainment processes associated with the F-16 weapon system offer a rich case study that provides context for the current generation of fighter-aircraft acquisition programs. Despite unforeseen funding shortfalls, the F-16 performed magnificently throughout the turbulent 1990s as a platform for employing precision munitions. The efforts of countless logisticians and acquisition professionals to devise adequate sustainment policies and initiatives in the late 1980s and early 1990s revealed an awareness of the need to keep pace with projected Cold War readiness requirements.

Logistics programmers used various metrics, such as NMCM/NMCS drivers, fix rates, maintenance man-hours/flight hour rates, break rates, time-change-item reliability, and mobility requirements to keep pace with the F-16's operational transformation.⁷⁰ The cumulative trends from this data were subsequently factored into aircraft design-change proposals as well as recommendations to incorporate forthcoming technologies with the potential to improve existing R&M specifications.⁷¹ In spite of these notable efforts to conduct sustainment planning within the logistics community, the sudden end to the Cold War, followed by a series of dramatic DoD fiscal-year budget cuts exposed the chink in the F-16's sustainment armor. Subsequent efforts to achieve cost savings within the USAF neglected to recognize the potential pitfalls associated with failing to provide adequate weapon system sustainment. Consequently, F-16 fleet health significantly deteriorated throughout the 1990s as mission-capable rates plummeted. A senior USAF officer who worked in both acquisitions logistics and major command logistics organizations in the 1980s/90s summarized the readiness deterioration as follows:

...just like design trades, people made budget and policy trades ... The early 90s was also a time of huge reform in acquisition/sustainment ... we threw out all the proven processes and went with "contractor systems." We didn't buy data, we significantly downsized our program offices, including removing most of the maintenance officers with fresh field experience, combined AFLC and AFMC, we closed two ALCs, we went

⁷⁰ Email from USAFE/DA4, Ramstein AB, GE 18 April 2005.

⁷¹ Ibid

to two level maintenance, and so on. I suspect you will not find a lone gunman who shot a hole in our readiness, but rather, a bunch of well-intentioned folks who took a thousand knives to readiness and we are still scarred and bleeding in a few areas.⁷²

The question that arises from this analysis is how could someone have prevented the F-16 readiness crisis? A methodology for projecting the effects caused by fluctuations in variables affecting mission readiness would have assisted in guiding some of the mid-life-cycle organizational, operational, and funding decisions which led to the spare-parts shortage in the 1990s. The next chapter will explore the use of sensitivity-analysis models to depict the degree of influence one factor has on another in a multivariable sortie-utilization equation. This methodology may alert future planners of the necessary balance between procurement and sustainment levels to meet service-life projections.

⁷² Ibid.

Chapter 4

F-16 Sustainment: Crunching the Numbers

Predicting the future is easy. It's trying to figure out what's going on now that's hard.
--Fritz R. S. Dessler

An operational unit's performance in accomplishing the annual Flying Hour Program (FHP) is the quantitative measure of mission readiness. As the primary tool for establishing aircrew proficiency, an operational wing's FHP represents a *report card*, of sorts, for unit-level commanders as well as budget programmers responsible for setting sustainment levels to provide support for flying operations. FHP requirements drive every facet of the Air Force operations enterprise, to include weapon-system force-structure and fleet-size, logistics infrastructure requirements, and personnel manning. Because of the direct link between flying hours and congressional appropriations, fluctuations in annual FHP levels receive a great deal of attention during fiscal-year budget-planning and programming activities.

For a new weapon system, FHP requirements positively correlate with weapon-system fleet size and future procurement. As explained in chapter 1, the apportionment of the Primary Aircraft Inventory (PAI) and Backup Inventory (BAI) is derived from the FHP and the corresponding logistics support necessary to achieve current and future readiness levels. As such, the fleet size equation is simply:

$$\text{FLEET STRENGTH (FS)} = \text{PAI} + \text{BAI} + \text{AR}$$

In this equation, unit FS is sum total of the number of aircraft apportioned as PAI, BAI and AR assets. PAI is the primary aircraft inventory for readiness requirements, BAI is the backup inventory to supplement aircraft losses due to unscheduled and depot maintenance activities, and

AR is the Attrition Reserve inventory to replace peacetime aircraft losses.⁷³

To accomplish FHP goals in sequence with established training requirements and pilot production goals, units monitor aircraft utilization (UTE) rates to optimize daily aircraft performance across the fleet. Hourly UTE rate goals in concert with the flying-hour program justify PAI levels and provide a gauge for the fleet's sortie generation capacity. When sortie capacity falls short of meeting FHP requirements, adjustments in PAI and/or UTE are typically necessary. The following formulas highlight the components of both PAI and UTE equations:

$$\text{PAI} = \text{FHP}/12 * \text{UTE}$$

and

$$\text{UTE} = \text{sorties/aircraft/day} * \text{FD}_{\text{month}} * (1 - \text{MX}_{\text{SCH}}) * (1 - \text{SP}) \\ * (\text{TL}) * [1 - (\text{TNMCM} + \text{TNMCS})]$$

where FD_{month} is the number of flying days per month, MX_{SCH} is the percentage of aircraft dedicated to mandatory scheduled maintenance, SP is the predetermined spare factor for wing scheduling practices, TL is percentage of total operational losses due to weather, crew availability etc.

Whereas the FHP and UTE reflect the production capacity of the fleet, the MC rate measures unit performance with respect to sustaining fleet health. During the procurement of aircraft weapon systems, forecasted MC rate standards play an important role in determining not only the near-term sortie capacity of the weapon system but also its long-term sustainability. As subset variables of the MC rate, TNMCM and TNMCS standards provide additional baselines to indicate the necessary sustainment infrastructure for weapon system support. Whereas, the TNMCM rate measures the training and management effectiveness of the maintenance complex, the TNMCS rate gauges the capacity of the repair cycle to provide parts in a timely and efficient manner. The codependent relationship of both TNMCM and TNMCS rate is depicted in the following equation.

$$\text{MC Rate} = 1 - [\text{TNMCM} + \text{TNMCS}]$$

⁷³ All the equations in this section were derived during discussions with Dr. Stephen Chiabotti and CMSgt (ret.) Bob Layman on 1 February 2005 and 15 April 2005.

An understanding of the interactions between maintenance metrics enables accurate sustainment forecasting during weapon system procurement planning. Historically, procurement efforts primarily have only forecast UTE and MC rates as indicators of future weapon system performance and aircraft availability. To a lesser degree has the total life-cycle sustainment of the weapon system been considered when formulating these requirements and establishing funding priorities. Issues such as projected structural deterioration, increased operational demands, and unforeseen aircraft modifications have received little attention when assigning initial MC and UTE rate standards. Consequently, as these weapon systems matured and began to experience early structural deterioration, sustainment planners resorted to *band-aid* remedies in order to preserve fleet health while meeting mission demands. The ensuing sustainment crisis exacerbated aircraft aging and ultimately degraded mission readiness.

The Value of Sensitivity Models

Quantitative modeling, via sensitivity analysis (SA), provides an objective methodology to measure the extent fluctuations among logistics and operations variables affect long-term sortie capacity. In the complicated process of marrying requirements to procurement solutions, sensitivity analysis tools help determine the relative degrees of importance among multiple variables in a decision analysis.⁷⁴ This *what-if* approach tests the viability of procurement decisions against stated requirements and provides a mechanism to identify potential areas of risk as the weapon system matures.⁷⁵ Efforts to optimize both aircraft sortie capacity and maintainability can significantly stretch procurement budgets already constrained by a healthy list of competing budget priorities. Consequently, future procurement efforts must rely on analytical techniques to help provide justification for sustainment requirements to meet long-term FHP requirements throughout a weapon system's service life. A quantitative-based approach to forecasting aircraft operational and sustainment requirements better supports service advocacy of major acquisition programs during fiscal year budget deliberations.

⁷⁴ Robert T. Clemen and Terence Reilly, *Making Hard Decisions* (Calif: Duxbury, 2001), 175-179.

⁷⁵ Samuel E. Bodily, *Modern Decision Making* (New York: McGraw-Hill Books, 1985), 57.

In Figures 7, 8, and 12, quantitative models using sensitivity analysis demonstrate how various operations and logistics factors affect near-term sortie capacity, long-term fleet health and required fleet strength.⁷⁶ Along with MC, TNMCM, and TNMCS inputs, independent variables such as PDM, scheduled maintenance, and phase factors are included to depict their collective influence on actual sortie capacity (UTE). Furthermore, the model accounts for management variables, such as daily turn rates, monthly fly days, and annual historical loss rates to present the most holistic depiction of the various factors which contribute to a wing organization's monthly utilization rate. This simulation of the constrained dichotomy between MAJCOM-level planning and wing-level execution shows the likely disconnects between weapon-system procurement, mission employment, and sustainment-forecasting processes. The ability to recognize the larger effects caused by subtle changes among aircraft readiness variables is a major step towards effective procurement and sustainment risk-management throughout a weapon system's service life.

The notional fleet operations and logistics profiles depicted in the following figures were constructed using actual data from operational fighter wing historical archives.⁷⁷ Using the annual MAJCOM-determined flying-hour program allocation as a baseline input, the model measures the relative sensitivity among various management and environmental variables and the extent they collectively affect wing sortie capacity. Additionally, the model allows planners to vary wing PAI levels against projected MC rates to determine the optimal balance needed to sustain sortie capacity requirements. The delta between the MAJCOM flying-hour allocation and wing sortie capacity, as calculated via sensitivity analysis, indicates necessary aircraft fleet strength to meet current and future mission demands. As the model proves, the optimization of the fleet's actual UTE rate via adjustments to various maintenance metrics can mitigate the negative effects of fleet strength shortfalls on mission readiness.

⁷⁶ Figures 7, 8, and 12 adapted by author from a sensitivity model produced by SMSgt (ret.) Mike Wasson, AETC Studies and Analysis. Input data obtained from USAF 1991 Statistical History, AFHRA, AF/IL MERLIN database, Air Force Safety Center, and CMSGT (ret.) Mike Mlodzik, former Maintenance Superintendent, Misawa AB Japan.

⁷⁷ Merlin database AF/IL accessed 2005

Notional Fleet Modeling analysis

FISCAL YEAR: **FY91 Flying Hours**

USAF "PA" PROGRAMMATIC FACTORS:

Annual Flying Hours	244,766
Accident Attrition Rate	3.8 /100,000 Hrs
Acft in Depot-level Repair	0% (BAA)

AETC Maint & Ops Variable Factors:

Mission Capable (MC) Rate	91%
Scheduled Maintenance	25%
Phase	5%
Depot	0%
Preflighted Spare Aircraft	15%
Sorties per Aircraft per Day	2
Flying Days per Month	20.4
Night & Cross-Country Sorties	0.0%
Weather Losses	
Operations Losses	
Mission Reliability (MR)	98.5%
Total Losses	3.0%
A/C Availability Tgt	99.0%
 TNMCS	 1.0%
NMCM 3yr. historical avg.	8.0%
NMCB historical avg.	2.0%
Sortie Length (Hrs)	1.4

Computed Operational Capability:

Primary Aircraft Inventory (PAI)	927
Daily Flyable Aircraft	801
 Daily Scheduled CAP	 511
Daily Scheduled CAP + Spares	601
Sorties/Day	1022
Day Sorties/Month	20844
Day+Night Sorties/Month	20844
"Effective" Sorties/Month	20219
Flying Hours/Month	28306
Utilization Rate	30.54

Capability vs Requirement Computation (PAI Driven):

Annual Flying Hour Capability	339,677
Annual Flying Hour Requirement	<u>244,766</u>
<i>Delta</i>	94,911

Aircraft Calculation:

Primary Aircraft Authorization (PAA)	927
Backup Aircraft Authorization (BAA)	0
BAI Attrition Reserve (BAI-AR):	<u>185</u>
Total Aircraft Authorization (TAA)	1112

Remarks:

31 Hours/Month per PAA Acft
 0% Aircraft in Depot Maintenance
 9.25 Class "A" Accidents per year
Authorized Aircraft

FIGURE 7

In Figure 7, a notional 1991 F-16C fleet is tasked to complete a 244,766 hour annual flying-hour program (FHP) with 927 possessed PAI aircraft. An 83 percent MC rate (current ACC standard) is assigned to this notional unit with typical scheduled maintenance and phase factors set at 25 and 5 percent respectively. With an average 20 days of flight operations per month (no weekend flying), a TNMCS rate of 1 percent, and an average sortie duration (ASD) of 1.4 hours per sortie, the squadron sortie capacity exceeds the FHP allocation with a surplus of over 94,000 hours (~67,000 sorties). The data set in Figure 7 assumes weapon system employment within the operational parameters set during initial procurement. Figure 7 represents the utopian set of conditions for F-16 weapon system employment supported by an adequately funded sustainment infrastructure.

In Figure 8, a notional representation of F-16 fleet health in FY1999 depicts the effects of increased mission demands and spare shortages on the MC and UTE rates. Relative to Figure 7, Figure 8 shows the sensitivity of a 17 percent MC reduction and extended phase inspection lengths (from 5 to 10 percent fleet rate) due to increased operational wear and spares shortages. These factors cause the notional fleet to fall short of its flying-hour program and highlight the effects of an additional 10 percent daily airframe deficit. When assessing the causal factors leading to the decreased MC rate, a major driver is the TNMCS variation from 1 to 18 percent in Figure 7. The disproportional TNMCS-increase, as opposed to the corresponding MC-rate decrease, highlights the exponential effect of inadequate spare stocks and 2-level maintenance repair cycle inefficiency on mission readiness.

Excessive unscheduled depot requirements also contributed to the decline in F-16 MC rates during the late-1990s, as increasing numbers of airframes throughout the fleet required extensive repairs to strengthen structural components. Consequently, F-16 sortie capacity and daily aircraft availability suffered as SLIP and Falcon-Up modification requirements forced PAI assets into depot status for indefinite time periods. Although these requirements occurred sporadically, the reduction in mission-ready aircraft negatively affected overall sortie capacity. As depicted in Figure 8, the 10 percent% depot maintenance factor represents an increase of the number of aircraft in depot status over a fiscal year.

Notional Fleet modeling analysis 2

FISCAL YEAR: FY99

USAF "PA" PROGRAMMATIC FACTORS:

Annual Flying Hours	278,971
Accident Attrition Rate	3.7 /100,000 Hrs
Acft in Depot-level Repair	5% (BAA)

AETC Maint & Ops Variable Factors:

Mission Capable (MC) Rate	74%
Scheduled Maintenance	25%
Phase	10%
Depot	10%
Preflighted Spare Aircraft	15%
Sorties per Aircraft per Day	2
Flying Days per Month	20.4
Night & Cross-Country Sorties	0.0%
Weather Losses	
Operations Losses	
Mission Reliability (MR)	98.5%
Total Losses	3.0%
A/C Availability Tgt	82.0%
 TNMCS	 18.0%
NMCM 3yr. historical avg.	8.0%
NMCB historical avg.	2.0%
Sortie Length (Hrs)	1.4

Computed Operational Capability:

Primary Aircraft Inventory (PAI)	1095
Daily Flyable Aircraft	656
 Daily Scheduled CAP	 418
Daily Scheduled CAP + Spares	492
Sorties/Day	837
Day Sorties/Month	17071
Day+Night Sorties/Month	17071
"Effective" Sorties/Month	16559
Flying Hours/Month	23183
Utilization Rate	21.17

Capability vs Requirement Computation (PAI Driven):

Annual Flying Hour Capability	278,197
Annual Flying Hour Requirement	<u>278,971</u>
<i>Delta</i>	-774

Aircraft Calculation:

Primary Aircraft Authorization (PAA)	1095
Backup Aircraft Authorization (BAA)	55
BAI Attrition Reserve (BAI-AR):	<u>206</u>
Total Aircraft Authorization (TAA)	1356

Remarks:

21 Hours/Month per PAA Acft
5% Aircraft in Depot Maintenance
10.32 Class "A" Accidents per year
Authorized Aircraft

FIGURE 8

Backup and Attrition Reserve Aircraft

In 1995, a GAO report on backup and attrition-reserve aircraft-inventory criteria raised concerns regarding the criteria used to establish backup inventories to support operational training maintenance as well as attrition replenishment.⁷⁸ An adequate back-up aircraft (BAA) fleet is a critical component to insuring weapon-system service-life. Whereas the BAA's purpose is to mitigate the effects of unscheduled maintenance and inspections to the PAA fleet, it more importantly ensures against degradation to readiness levels caused by required late life-cycle depot maintenance and structural modifications. Depot-level sustainment, whether programmed or not, is an inevitable component of a weapon system's viability and warrants continuous assessment throughout its service life. The use of a fleet-modeling analysis, as previously demonstrated, can assist planners in accommodating unscheduled depot requirements by

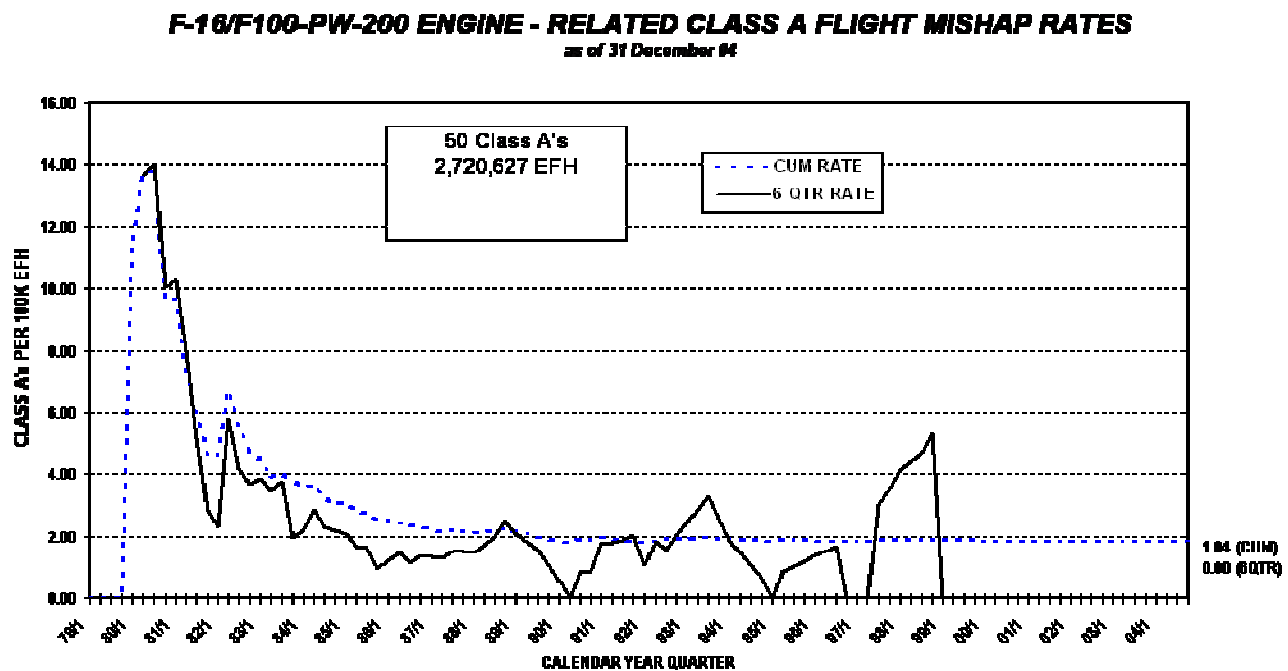


FIGURE 9

⁷⁸ US General Accounting Office. *Aircraft Requirements-Air Force and Need to Establish Realistic Criteria for Backup Aircraft*, GAO/NSIAD-95-180, Washington D.C.: 29 September 1995.

F-16/F110-GE-129 ENGINE - RELATED CLASS A FLIGHT MISHAP RATES

as of 31 December 04

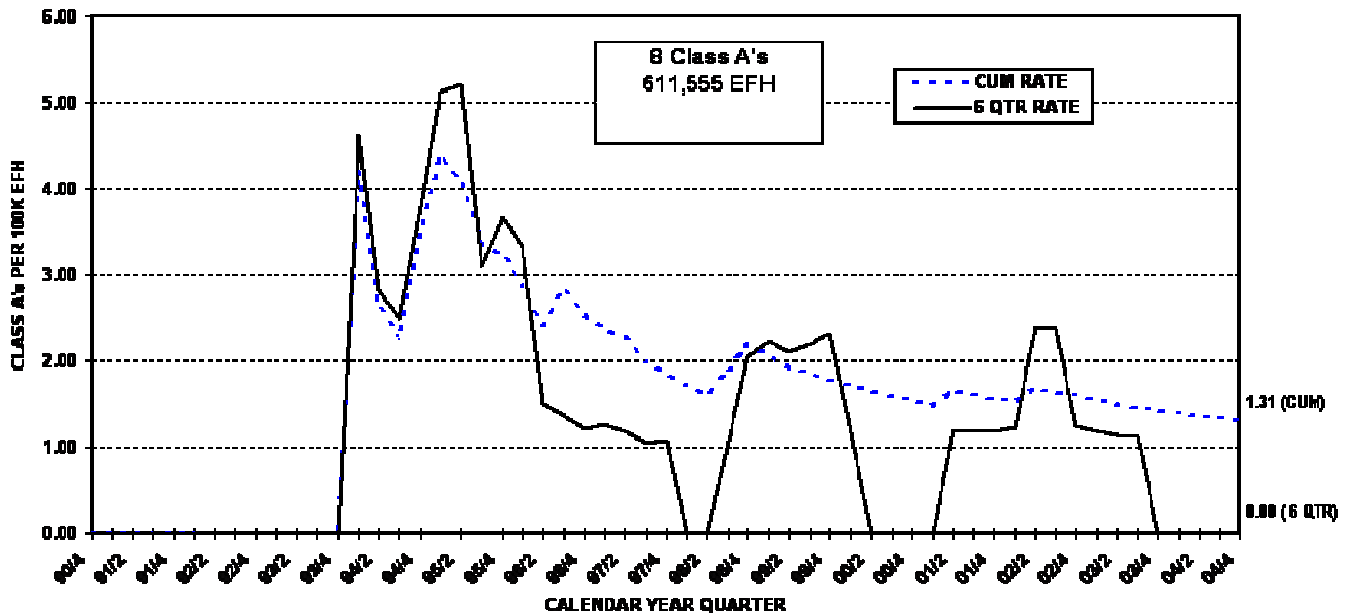


FIGURE 10

forecasting the effects of temporarily-reduced aircraft availability on readiness levels and fleet health.

Not only does Figure 8's notional analysis highlight the effects of structural deterioration, but also the increased attrition due to F-16 engine failures. During FY 99 alone, engine failures accounted for 8 class-A mishaps and represented the largest driver in a 42 percent attrition-rate increase. Additionally, from FY 97-01, engine malfunctions were causal factors in 25 class-A mishaps.⁷⁹ This dilemma occurred as a result of the lack of modernization funding to update critical components and address risk factors associated with operating a single-engine weapon system. Figures 9 and 10 display the trend of class-A mishaps throughout the 1990s for both Pratt & Whitney and General Electric manufactured engines.⁸⁰

The size of the F-16 attrition reserve fleet is a function of a weapon system's annual average peacetime loss rate and the number of years the aircraft is projected to

⁷⁹ Capt John Schroeder, Air Combat Command Flight Safety Office, ACC/DO, Operations Division, Interview. 15 March 2001, quoted in Bryan Manes, "Extending USAF F-16 Force Structure" (Air Command and Staff College Research Paper, 2001), 21.

⁸⁰ Figures 9 and 10 found in Air Force Safety Center statistical data. 1 May 2005, n.p. On-line, Internet, 1 May 2005, available from <http://afsafety.af.mil/AFSC/RDBMS/Flight/stats/statspage.html>.

exist in the USAF inventory.⁸¹ Figures 7 and 8 depict AR fleet size sensitivity to fluctuations in annual attrition rates. Current safety metrics, as determined by the Air Force Safety Center, assess aircraft attrition by reporting the number of class-A (total loss) accidents per 100,000 flying hours. As Figure 10 indicates, unpredictable trends of high and low class-A incidents occur due to a various design and performance anomalies over a weapon system's service life.

The sensitivity modeling contribution to AR forecasting rests in its capability to identify risk factors regarding weapons system design characteristics. The F-16's single-engine design, for example, generates a higher attrition projection than its dual engine counterpart (the F-15) and consequently requires a larger AR fleet to support readiness demands. Conversely, AR fleet requirements can also decrease as weapon-system reliability and safety records stabilize due to material reliability and pilot experience.

F016C ANNUAL FLIGHT SAFETY STATISTICS Last updated March 23, 2005											
	NON-RATE	CLASS A		CLASS B		DESTROYED AIRCRAFT		FATALITIES		FLIGHT HOURS	
YEAR	Count	Count	Rate	Count	Rate	Count	Rate	Pilot	Total	Year	Cum
FY85	0	0	0.00	0	0.00	0	0.00	0	0	6139	6139
FY86	0	1	2.58	0	0.00	1	2.58	0	0	38791	44930
FY87	0	5	6.14	2	2.46	5	6.14	3	3	81418	126348
FY88	0	13	10.45	2	1.61	12	9.64	4	6	124418	250766
FY89	0	7	4.12	0	0.00	8	4.71	3	3	169814	420580
FY90	0	5	2.44	3	1.46	6	2.93	2	2	204883	625463
FY91	0	10	3.78	1	0.38	10	3.78	2	2	264417	889880
FY92	0	8	3.07	0	0.00	8	3.07	1	1	260723	1150603
FY93	0	10	3.92	1	0.39	10	3.92	3	3	254945	1405548
FY94	0	11	4.36	2	0.79	10	3.57	2	2	252018	1657566
FY95	0	7	2.52	1	0.36	6	2.16	1	1	277322	1934888
FY96	0	8	2.85	3	1.07	7	2.49	0	1	280886	2215774
FY97	0	5	1.77	0	0.00	5	1.77	0	0	282623	2498397
FY98	0	10	3.52	0	0.00	9	3.17	2	2	283938	2782335
FY99	0	13	4.65	2	0.72	11	3.94	2	2	279339	3061674
FY00	0	8	2.97	2	0.74	8	2.97	2	2	269077	3330751
FY01	0	9	3.31	5	1.84	10	3.68	3	4	271981	3602732
FY02	0	7	2.33	3	1.00	6	1.67	2	2	299922	3902654

⁸¹ Chairman of the Joint Chiefs of Staff Instruction, *Standardized Terminology for Aircraft Inventory Management*, 3 October 2001.

FY03	0	10	3.41	6	2.04	10	3.41	2	2	293644	4196298
FY04	0	2	0.70	5	1.75	2	0.70	1	1	285464	4481762
LIFETIME	0	149	3.32	38	0.85	144	3.21	35	39	4481762	4481762
5 Yr Avg	0.00	7.20	2.54	4.20	1.48	7.20	2.54	2.00	2.20	284017.60	
10 Yr Avg	0.00	7.90	2.80	2.70	0.96	7.40	2.62	1.50	1.70	282419.60	

FIGURE 11⁸²

Figure 12 reflects a notional infusion of FY '00 spare parts funding to reverse the sluggish F-16 MC rates depicted in Figure 8. In an effort to highlight the readiness challenges associated with the F-16 during this period, defense analyst Bert Cooper, advocated Congress increased F-16 procurement to avert a gap in fighter aircraft readiness: "F-16 Supporters argue that procurement of the aircraft should continue in order to sustain the multi-role fighter force through the early 2000s, noting that normal peacetime attrition will result in inventory shortages around the turn of the century and well before any JAST-derived (JSF) aircraft is likely to be in production."⁸³ This assessment reflected the depleted state of the F-16 program at the turn-of-the century as a result of operational demands and inadequate sustainment support. Despite the increased spare-parts funding, the recovery of the F-16 fleet still remained an uphill battle due to an increasing number of aircraft reaching retirement age. Furthermore, continually aging aircraft presents tougher readiness challenges as maintenance-repair times increase to prepare aircraft for the daily flying schedule. These challenges place a strain on near-term flight scheduling as health-of-fleet planning becomes a driving variable in FHP management.

FHP Management and Average Sortie Duration Factors

Figure 12 reveals that an increase in MC rate, alone, is not enough to assure adequate sortie capacity to meet externally directed UTE rates. FHP management challenges, such the scheduling of average sortie duration (ASD), monthly fly days, and sortie turn rate, also play a significant role in optimizing fleet sortie capacity and maintenance capability. As a weapon system matures, FHP management becomes increasingly important, given dwindling resources and constrained budgets.

⁸² Air Force Safety Center, Available from <https://sas.kirtland.af.mil/irms/IrmsResultsAction.do?reportName=annual&mds=F016C&disc=aviation>.

⁸³ Bert Cooper, *F-16 Aircraft Issues: Debate over Procurement*. Congressional Research Service Report for Congress 94-642 F. Washington D.C.: The Library of Congress, 1994.

Notional Fleet Modeling analysis 3

Fiscal Year: FY03

USAF "PA" PROGRAMMATIC FACTORS:

Annual Flying Hours	292,824
Accident Attrition Rate	0.7 /100,000 Hrs
Acft in Depot-level Repair	5% (BAA)

AETC Maint & Ops Variable Factors:

Mission Capable (MC) Rate	77%
Scheduled Maintenance	25%
Phase	5%
Depot	5%
Preflighted Spare Aircraft	15%
Sorties per Aircraft per Day	2
Flying Days per Month	20.4
Night & Cross-Country Sorties	0.0%
Weather Losses	
Operations Losses	
Mission Reliability (MR)	98.5%
Total Losses	3.0%
A/C Availability Tgt	85.0%
TNMCS	15.0%
NMCM 3yr. historical avg.	8.0%
NMCB historical avg.	2.0%
Sortie Length (Hrs)	1.3

Computed Operational Capability:

Primary Aircraft Inventory (PAI)	1047
Daily Flyable Aircraft	728
Daily Scheduled CAP	464
Daily Scheduled CAP + Spares	546
Sorties/Day	928
Day Sorties/Month	18925
Day+Night Sorties/Month	18925
"Effective" Sorties/Month	18357
Flying Hours/Month	23864
Utilization Rate	22.79

Capability vs Requirement Computation (PAI Driven):

Annual Flying Hour Capability	286,366
Annual Flying Hour Requirement	<u>292,824</u>
<i>Delta</i>	-6,458

Aircraft Calculation:

Remarks:

Primary Aircraft Authorization (PAA)	1047	23 Hours/Month per PAA Acft
Backup Aircraft Authorization (BAA)	52	5% Aircraft in Depot Maintenance
BAI Attrition Reserve (BAI-AR):	<u>41</u>	2.05 Class "A" Accidents per year
Total Aircraft Authorization (TAA)	1140	Authorized Aircraft

FIGURE 12

Figure 12 also highlights how the MC and UTE rate sensitivity to ASD significantly influences overall sortie capacity. An ASD reduction of a mere 7 percent (six minute for a typical sortie) from the previous scenario creates a notable capacity deficit with respect to meeting FHP requirements. Whereas other logistics factors are more heavily influenced by the availability of resources and infrastructure, ASD is more locally controlled and dependent on environmental factors such as airspace constraints, geographical characteristics, air traffic density, and aircraft fuel efficiency. Additionally, ASD management also affects overall maintenance capability with respect to the sortie-turn-rate volume and phase-flow efficiency. The wing-level management challenge of finding the right balance between scheduling efficiency and training effectiveness is critical to achieving optimal operational performance without overextending manpower capacity.

Operational training constraints influence ASD and must factor into long-range scheduling to meet FHP requirements. Through careful attention to FHP effects caused by the slight ASD fluctuations, planning efforts to determine training requirements must account for this unusually high sensitivity. Furthermore, ASD management serves as a barometer for projecting fleet-wide scheduled maintenance and phase-inspection frequency, which ultimately determines daily airframe availability. The analysis portrayed in Figure 12 sheds light on the challenges associated with maintaining a delicate balance between operational effectiveness and long-term fleet health. The challenges become increasingly difficult when MC and UTE standards do not account for base-level environmental considerations, training conditions, or sustainment capacity. Consequently, wing-level organizations shoulder the burden to reconcile conflicting operational requirements and logistics demands to achieve readiness goals.

Conclusion

The sensitivity analysis drills, in Figures 7, 8, and 12, for the F-16 life cycle demonstrate that logistics planners can iteratively test future weapon system capabilities against FHP requirements under various environmental conditions. Although sensitivity models are not *crystal balls*, they do provide a foundation for formulating procurement strategies for long-term weapons system purchases. The F-16's dynamic evolution proves the necessity of the iterative modeling drills demonstrated in Figures 7, 8, and 12

as a means to highlight the effects of sustainment trade-offs when making weapon-system procurement decisions. Comprehensive sensitivity modeling, as previously outlined, could have alerted planners to the impending sustainment crises which occurred as a result of increasing F-16 operational demands without adequate procurement and sustainment funding. The projections derived from such an analysis subsequently could have supported advocacy for increased weapon-system budgetary support. The F-16 case study shows how evolutions in operational capabilities as well as changes in political contexts can affect long-term sustainment and, ultimately, aircraft readiness. Successful business-world application of sensitivity modeling as an forecasting tool to project profit margins should serve as ample proof of its potential to aid in aircraft procurement and sustainment forecasting. As evidenced by the F-16's sustainment challenges, the quantitative modeling of weapon system readiness factors is essential to constructing an optimal balance between operational capacity and sustainment demands.

Current procurement efforts such as the F-35 Joint Strike Fighter rely on the historical lessons of the F-16 experience to build and employ a cost-effective aircraft weapon system for the USAF and its allies. Accordingly, similar design characteristics, such as the single-engine concept and multi-role operational capabilities, are integrated into the development of the F-35 weapon system. In order to prevent a recurrence of the F-16 sustainment crisis, however, efforts to develop a sound sustainment strategy and supporting infrastructure are critical to the long-term viability of the F-35 program. Furthermore, the added dimension of a jointly developed weapon system design to support inter-service mission demands adds an exponential level of complexity to the sustainment challenge. The next chapter will examine the F-35 program and assess whether the JSF concept has, to date, avoided the pitfalls of its predecessor.

Chapter 5

Procuring and Sustaining the JSF

Aircraft maintenance metrics are important. Don't let anyone tell you differently! They are critical tools to be used by maintenance managers to gauge an organization's effectiveness and efficiency. In fact, they are roadmaps that let you determine where you've been, where you're going, and how (or if) you're going to get there. Use of metrics allows you to flick off your organizational pilot and actually guide your unit. But they must be used correctly to be effective. Chasing metrics for metrics' sake is a bad thing and really proves nothing. A good maintenance manager will not strive to improve a metric but will use them to improve the performance of the organization.

*--Brig Gen Terry L. Gabreski
Metrics Handbook for Maintenance Leaders*

Due to increased program costs, schedule delays, and a reduced production schedule; the size of the Joint Strike Fighter (JSF) program is currently under congressional scrutiny. As DoD's most expensive acquisition program, the JSF is the linchpin to the nation's next-generation tactical strategy. Furthermore, initial JSF procurement is expected to close the impending fighter force structure deficit, as current aging aircraft systems retire without replenishment. Based on the historical lessons of procurement efforts such as the F-16, the DoD recently formulated a new sustainment methodology which focuses on evolutionary, knowledge-based principles. This change provides a framework to incorporate technological innovations, which occur after the system development decision (SDD), into a weapon system's production cycle. The current JSF procurement strategy has, however, abandoned this evolutionary concept in favor of an approach which schedules larger aircraft delivery increments early in the weapon system's life cycle. A faster JSF low-rate initial production (LRIP) rate risks

outpacing the full development of critical aircraft design technologies and could potentially create late life-cycle modification requirements for a significant portion of the fleet. Moreover, inadequate sustainment provisions could increase the probability of aircraft structural deterioration. In order to avoid the exorbitant costs associated with late life-cycle deterioration, procurement planners need to conduct early analyses to forecast aircraft sustainability throughout the JSF's projected service life. The sheer size and varied operational demands of the F-35 acquisition will require new life-cycle management approaches based on variable-performance-metrics standards and fiscal-year-programming flexibility.

The TFX Debacle

The JSF program is not the first attempt to design, develop, and produce a single aircraft to fulfill multiple missions across various military services. The Tactical Fighter Experimental (TFX) program, proposed by former Secretary of Defense Robert McNamara in 1961, was the first large-scale effort to procure an aircraft weapon system using a joint development approach:

I believe that the development of a single aircraft of genuine tactical utility to both services in the projected time frame is technically feasible. A single aircraft for both the Air Force tactical mission and the Navy fleet air defense mission shall be undertaken. The Air Force shall proceed with the development of such an aircraft ... Changes to the Air Force tactical version of the basic aircraft to achieve the Navy mission shall be held to a minimum.⁸⁴

The TFX concept advocated a single-aircraft design to fulfill both Navy fleet air defense and Air Force tactical long-range nuclear/conventional mission requirements. As a replacement for both the Air Force F-105 and the Navy F-4 fighter aircraft, the TFX program sought to achieve substantial savings using a common development approach in all phases of aircraft development, testing, and production as well as life-cycle-logistics sustainment efforts. Key to the common development approach included the development of a homogenous spare-parts infrastructure to provide responsive and dependable support to front-line operational units. Secretary McNamara recognized that aircraft readiness rates were a function of spare-parts availability. As such, the only way

⁸⁴ Senate, *TFX Contract Investigation*, 88th Cong., 1964, Secretary of Defense Memorandum, September 1, 1961, pt 6:1514.

to ensure adequate stockpiles while minimizing costs was to emphasize commonality throughout the TFX development as a program objective. The quest for commonality, however, ultimately hindered the dual-mission development of the TFX, which resulted in a compromised design that failed to meet either service's initial requirements. In a memo to Secretary McNamara, Acting Secretary of the Navy Paul B. Fay attempted to warn of the futility of proceeding with a joint-development aircraft program:

The aircraft and the Navy have been mindful of your interest in the TFX, and have used every means to respond to your guidance. However, in the case of the TFX, it has not been practicable to reach an agreement on the characteristics of the TFX and at the same time fulfill the stated military mission requirements ... In light of the fundamental differences in the basic requirements for the Navy versus Air Force fighters, it is not surprising that a compromise design between Navy and Air Force requirements would produce an aircraft that would be considerably below optimum for either service.⁸⁵

The TFX program ultimately failed to meet its original intent of providing a joint aircraft to meet Navy and aircraft mission requirements. The original General Dynamics contract to produce 1726 aircraft was reduced by 66 percent after cancellation of the Navy's F-111B version and the scaled-down production of the Air Force's F-111A model.⁸⁶ Additionally, the \$1 billion projected cost savings from joint development and production disappeared as a result of the reduced fleet size and the cost of modifications to recover air-to-ground capabilities for subsequent Air Force TFX versions. Original airframe costs estimates of \$3.4 million ballooned to \$16.6 million for only 489 production airframes.⁸⁷

Second Time Around—The JSF

Whereas the TFX program began with Secretary McNamara forcing the Navy to integrate its fleet air defense mission requirements into an existing Air Force design construct, the current JSF program has avoided this mistake by infusing jointness from its inception. From alternating management control between Air Force and Navy leaders, to assigning integrated military/industry design teams, the JSF has attempted to develop and produce a weapon system that achieves commonality without compromising mission

⁸⁵ US Senate, *TFX Contract Investigation*, 88th Cong., 1964, Secretary of Defense Memorandum, August 22, 1961, pt 6:1464.

⁸⁶ US Senate, *TFX Contract Investigation, Second Series*, 91st Cong., 1970, pt. 1:82.

⁸⁷ *Ibid.*, pt. 1:74.

effectiveness. Second, the JSF effort uses a cost-as-an-independent-variable (CAIV) concept to balance requirements demands with congressional mandates for reduced program risks and life-cycle costs. Finally, the JSF has prioritized supportability for both long-term life-cycle sustainment and short-term deployability to assure the weapon system's capability to meet future contingencies across the spectrum of military conflict. By instituting a *family- of-aircraft* approach to building commonality between structural, propulsion and avionics components, the JSF program intends to meet both the cost constraints of developing an affordable aircraft weapon system and the increasing demands for evolutionary improvements in combat capability.

Today's Joint Strike Fighter program originated from the Joint Advanced Strike Technology (JAST) concept, which sought to develop new technologies for integration in a next-generation tactical aircraft. In the mid-1990s, as JAST technological concepts took shape, Congress directed that the ongoing Advanced Short Take-Off/Vertical Landing (ASTOVL) program become part of the JAST/JSF program to consolidate development efforts for the nation's future strike/fighter aircraft.⁸⁸ During a concept-demonstration phase, in the late 1990s, Lockheed Martin and Boeing corporations each fielded experimental aircraft to validate government-stipulated flight objectives and compete for the lucrative JSF development and production contract.⁸⁹ Concurrently, the Pratt & Whitney Corporation along with a combined General Electric/Rolls Royce team were selected to develop and produce interchangeable JSF propulsion systems as part of an acquisition strategy designed to reduce life-cycle technological risks.⁹⁰ On 26 October 2001, Lockheed Martin won prime contractor designation for the JSF along with Northrup Grumman and BAE corporations named as principal partners.⁹¹

Two additional JSF designs include the conventional take-off and landing (CTOL) and carrier variants (CV) which will provide next-generation tactical aircraft for the Air Force (AF) and Navy. Despite subtle differences in each of the variants based on mission requirements, the multi-variant JSF design strives to deliver an affordable, lethal,

⁸⁸ F-35 Joint Strike Fighter Program, *History*, On-line. Internet, 30 May 2005, available from <http://www.jsf.mil>.

⁸⁹ Christopher Bolkom, "Report for Congress, Joint Strike Fighter (JSF) Program: Background, Status, and Issues", 8 April, 2003, On-line, Internet, 25 May 2005, available from <http://www.globalsecurity.org/military/library/report/crs/RL30563.pdf>

⁹⁰ F-35 Joint Strike Fighter Program-On-line.

⁹¹ Ibid.

survivable, and supportable weapon system to its entire customer base from a single development and production program.⁹² A key element to achieving these goals rests in the development efforts to build systems commonality into all three aircraft variants. From the manufacturing processes on the assembly line to the integration of maintenance support systems, DoD requirements stipulate that JSF development and production efforts prioritize service interoperability as a cornerstone to developing an affordable weapon system throughout its intended life cycle.⁹³ Additionally, requirements dictate a near 100-percent component-commonality in avionics suites across the variants, in an effort to reduce spare parts requirements and minimize the deployment footprint during contingency operations.⁹⁴

From the very beginning, the FMS potential of the JFS was considered by Congress as a means to defray development and production costs of the aircraft. Toward this end, the JSF STOVL variant has become a key part of increasing critical to assuring the program's overall marketability to US allies. The United Kingdom (UK), in particular, expressed early interest in the STOVL variant as a viable replacement for its aging Harrier fleet.⁹⁵ In 1995, via a memorandum of understanding (MOU), the UK entered into the program as a collaborative partner in JSF requirements definition and initial aircraft design efforts. This MOU set the foundation for additional UK contributions which included \$200 million and \$2 billion investments during the concept definition and system-development phases respectively.⁹⁶ Later allied participation included Turkey, Italy, Denmark, Norway, and the Netherlands, who signed similar MOUs and also committed financial contributions.⁹⁷ Additional countries accepted roles in JSF System Development that entailed larger financial commitments ranging from \$250 million to \$1.25 billion over an 11-year period.⁹⁸

Performance-Based Logistics

⁹² Ibid.

⁹³ Bolkom, On-line.

⁹⁴ F-35 Joint Strike Fighter Program, On-line.

⁹⁵ Bolkom, On-line.

⁹⁶ Ibid.

⁹⁷ Ibid.

⁹⁸ Ibid.

The integration of performance-based logistics (PBL) principles is a key component of the JSF acquisition strategy and total life-cycle sustainment plan. By definition:

Performance-Based Logistics is the acquisition of support as an integrated, affordable, performance package designed to optimize system readiness and meet performance goals for a weapon system through long-term support arrangements with clear lines of authority and responsibility. Performance-based strategies focus on achievement of performance outcomes, not the transactional products or services that enable those outcomes.⁹⁹

Recent revisions to DoD-5000 series regulations mandate that program managers tailor PBL strategies to optimize weapon-system effectiveness while minimizing sustainment costs and logistics footprints.¹⁰⁰ As nebulous as the concept sounds, the PBL construct consists of an extensive network of customers, suppliers, and acquirers who work together to increase visibility, minimize costs, and reduce risks across the program life cycle.¹⁰¹ The mechanism used to guide this process is the performance-based agreement (PBA) which specifies objectives, outcomes, measures, resource commitments, and stakeholder responsibilities for the numerous contractual relationships in a given acquisition program.

The PBA serves as the bridge between stipulated requirements and the negotiated level of performance and support necessary to satisfy customer needs. The key difference in the PBA concept, as opposed to previous product-based methodologies, is that the agreements identify various ranges in performance outcomes accompanied by targets for each level of capability provided.¹⁰² Additionally, PBAs delineate constraints during normal and surge operations while specifying provisions for unexpected changes in OPTEMPO and fiscal-year funding. PBAs provide a useful tool to explicitly state expectations and capabilities for steady-state operations in addition to establishing a framework for adjusting levels of support as warfighting requirements change.

⁹⁹ JSF Program Office (JSFPO) Performance Based Agreement Planning. Briefing. May 2005

¹⁰⁰ Defense Acquisition Guidebook, n.p. On-Line, Internet, 15 May 2005,. available from http://akss.dau.mil/dag/DoD5000.asp?view=document&rf=GuideBook\IG_c5.3.asp.

¹⁰¹ JSFPO PBA Planning Briefing.

¹⁰² Ibid.

The JSF PBL strategy is based on an end-to-end partnering approach supported by strategic milestones to build accountability into the logistics and sustainment plan.¹⁰³ This cradle-to-grave network consists of warfighters, contractors, industry, and program managers who continually communicate to refine customer requirements and supplier capabilities to meet program goals. A key component to this network is the relationship between the military service/allied nation customers and the JSF Program Office (JSFPO). To facilitate this important partnership, the proposed JSF PBL plan sets partnering mandates which require both the JSFPO and the services to negotiate and agree on PBAs to include defining product metrics.¹⁰⁴ These metrics will be tailorable to specific stakeholders accounting for the variations in mission requirements and warfighting objectives. Despite subtle differences between end-users, however, the overarching PBL metrics criteria, as directed by the Under Secretary of Defense for Acquisitions, Technology, and Logistics (USD-ATL), will focus on operational availability and reliability, cost per unit usage, and logistics footprint and response time. According to OSD guidance:

PBL metrics should support these desired outcomes [metrics criteria]. Performance measures will be tailored by the Military Departments to reflect specific Service definitions and the unique circumstances of the PBL arrangements ... the purpose of PBL is 'buying performance,' what constitutes 'performance' must be defined in a manner in which the achievement of performance can be tracked, measured, and assessed. The identification of top level metrics achieves this objective.¹⁰⁵

The JSF PBL system, in theory, presents an evolutionary advancement in total life-cycle management and offers the promise of seamless operations between maintenance and supply communities charged with sustaining readiness demands.

Autonomic Logistics Information System

The integration of performance-based requirements represents an evolutionary leap toward effective JSF life-cycle sustainment; however, PBL is not achievable without a viable maintenance and logistics information architecture. The Autonomic Logistics Information System (ALIS) offers an integrated solution for the effective management of JSF management and logistics programs. As a comprehensive network, ALIS is enabled

¹⁰³ Ibid.

¹⁰⁴ Ibid.

¹⁰⁵ Ibid.

by two technological constructs: 1. a constellation of diagnostic sensors to detect impending faults via reasoning algorithms and 2 a supporting information architecture to quickly process information for responsive action throughout the PBL infrastructure.¹⁰⁶ The development of ALIS was prompted by the increasing technological complexity of DoD weapon systems and the corresponding activities required to maintain them. As such, ALIS is designed specifically to reduce aircraft NMC time and maintenance costs, and eliminate fault-detection inaccuracies.¹⁰⁷ The ALIS concept is central to JSF life-cycle sustainability and the successful implementation of the PBL philosophy.

As the ALIS is central to PBL, a fully-functional prognostics and health-management system (PHM) manages the complex aircraft diagnostic, fault-detection/isolation, and component-repair processes to support ALIS. In theory, PHM is an embedded aircraft system that detects aircraft system faults, performs on-board diagnostics/prognostics, and even delays unnecessary maintenance in lieu of internal system reconfigurations to facilitate continued weapon system operation.¹⁰⁸ Combined with the Joint Distributed Information System (JDIS), the PHM fuels the ALIS capability to detect and analyze impending fault conditions and subsequently disseminate relevant information across the logistics and sustainment enterprise.¹⁰⁹ The PHM system's efficiency will ultimately minimize maintenance man-hours per flight hour by utilizing JDIS capabilities to provide immediate clarity regarding aircraft mission status upon its return from operational sorties. Furthermore, the PHM/JDIS collective architecture provides timely aircraft status to the logistics sustainment enterprise in order to kick-start necessary repair cycle actions.¹¹⁰ Current legacy aircraft weapon systems are unable to provide immediate fault detection and system diagnostics while still in flight. This

¹⁰⁶ W. Scheuren, "Safety & The Military Aircraft Joint Strike Fighter Prognostics & Health Management." 34th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit July 13-15, 1998, Cleveland, Ohio: 1-7. American Institute of Aeronautics and Astronautics, 1801 Alexander Bell Drive, Suite 500, Reston VA, July 1998, in Michael E. Malley, "A Methodlogy for Simulating the Joint Strike Fighter's (JSF) Prognostics and Health Management System" Thesis, Air Force Institute of Technology, March 2001, 1, On-Line, Internet, 14 May 2005 available from <http://www.stormingmedia.us/50/5031/A503193.html>.

¹⁰⁷ Michael E. Malley. "A Methodlogy for Simulating the Joint Strike Fighter's (JSF) Prognostics and Health Management System" Thesis, Air Force Institute of Technology, March 2001, 2, On-Line, Internet, 14 May 2005 available from <http://www.stormingmedia.us/50/5031/A503193.html>.

¹⁰⁸ Ibid, 2.

¹⁰⁹ Ibid, 1.

¹¹⁰ Ibid, 2.

limiting factor subsequently hinders sustainment responsiveness and relegates the supporting network of flightline maintainers, organic depots, and contractors to a reactive posture. A typical scenario under the existing construct occurs in the following sequence: 1. an aircraft returns to base with an unknown system fault 2. maintenance personnel implement intensive troubleshooting procedures to isolate the fault and determine root causes 3. the logistics sustainment infrastructure initiates measures to replace malfunctioning parts only after notification from flightline maintainers and 4. the aircraft is designated non-mission capable until the part arrives and installed on the aircraft.¹¹¹ The cumulative time spent to repair the malfunctioning aircraft represents a significant, unrecoverable opportunity cost to fleet readiness and manpower resources. Under the conceptual PHM system, this opportunity cost diminishes significantly due to

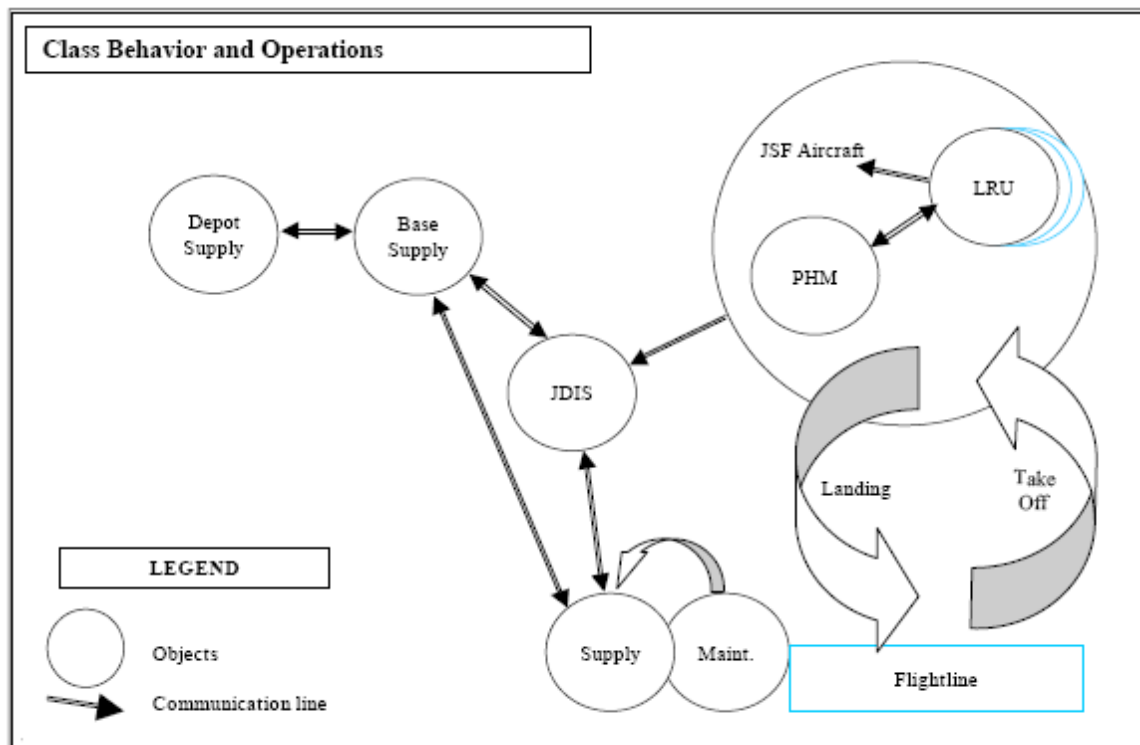


Figure 13: JSF ALS Components¹¹²

maintenance crews only performing the necessary diagnostic tests derived from prognostic analysis and relayed through the JDIS. Furthermore, through the *predictive alerts* enabled by PHM systems, the logistics enterprise is not hostage to the manpower

¹¹¹ JSF Program Office, Mr. Andy Hess, JSF PHM Lead, "The Joint Strike Fighter Prognostics and Health Management," Briefing, JSFPO, Date unknown.

¹¹² Malley, 6.

limitations of maintenance troubleshooting and can immediately respond to unit parts and equipment requests.¹¹³

Bumps in the Road

In contrast to the JSF's joint development and numerous innovations in technologies and logistics processes, the program's development has not been without challenges in the area of technology/design integration. Since 2001, JSF engineers have faced several challenges in meeting the stated purpose of balancing customers' competing mission demands. The journey met its toughest obstacle in February 2004 when initial estimates proved wrong and resulted in a heavier-(by as much as 3000 pounds)-than anticipated gross aircraft weight.¹¹⁴ This condition threatened to curtail development of the STOVL variant due to its unique flight-envelope parameters. Because of the significance of the aircraft-weight problem, the entire development effort refocused its energies on searching for alternatives to help steer the aircraft design proposal back on track.¹¹⁵ A Lockheed-led contractor team instituted a massive specialized working group named the STOVL Weight Attack Team (SWAT) which consisted of 500 engineers and managers to tackle the complex problem of trimming the excess weight off of the aircraft design.¹¹⁶ The reduction initiative not only affected the JSF air vehicle but also required significant revisits to the weapon system as a whole. From a systems-engineering perspective, the retro-design activities required a revamping of many decision-making procedures while monitoring the strict technical controls intended to mitigate the effects of the subtle engineering challenges identified by the SWAT effort.¹¹⁷ Furthermore, the improved design submitted by the SWAT team prompted the revalidation of JSF production processes and delivery schedules to ensure the program stayed within budget parameters.

The airframe-weight-reduction initiative also posed a challenge to the momentum of JSF propulsion development. Throughout the 2003-2004 timeframe, the Lockheed/Pratt & Whitney/GE/Rolls Royce team committed to finding innovative ways

¹¹³ Malley, 12-13.

¹¹⁴ F-35 Year in Review 2004, n.p. On-Line. Internet, 15 May 2005, available from http://www.jsf.mil/downloads/down_documentation.htm.

¹¹⁵ Ibid.

¹¹⁶ Ibid.

¹¹⁷ Ibid.

to increase propulsion efficiency as part of the SWAT weight reduction effort on the STOVL variant.¹¹⁸ One innovation was the optimization of the STOVL nozzle design to generate more thrust during hovering and short-takeoff maneuvers. The result of this effort yielded a 700-pound thrust increase in *hover mode* and a 2800 pound boost to the *short takeoff axial thrust* for the JSF STOVL variant. In addition to the challenges to the STOVL variant, the continued development of the CTOL and CV engine design remained a high priority in order to meet scheduled early-2006 flight-test milestones

As a result of the engineering challenges encountered over four-year period since 2001, the JSF program garnered considerable scrutiny from a program-management perspective. An April 2005 GAO study highlighted the execution of the current JSF business case, given increased cost estimates and reduced production quantities:

Increased program costs, delayed schedules and reduced quantities have diluted DOD's buying power and made the original JSF business case unexecutable. Program instability at this time makes the development of a new and viable business case difficult to prepare. The cost estimate to fully develop the JSF has increased by more than 80 percent. Development costs were originally estimated at roughly \$25 billion. By the 2001 system development decision, these costs increased almost \$10 billion, and by 2004, costs increased an additional \$10 billion, pushing total development cost estimates to nearly \$45 billion. Current estimates for the program acquisition unit cost are about \$100 million, a 23 percent increase to the estimated program cost. At the same time, procurement quantities have been reduced by 535 aircraft and the delivery of operational aircraft has been delayed.¹¹⁹

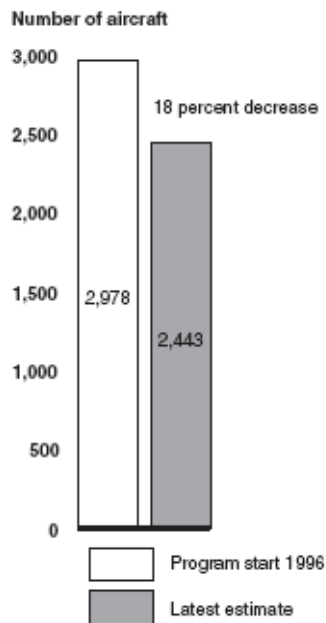
The dilemma described above is a product of both aircraft design challenges associated with the STOVL-variant weight reduction and the lagging development of JSF knowledge milestones. Program managers, eager to find efficiencies to mitigate the effects of these challenges, explored ways to reduce the climbing costs while not deviating from development and production schedules. One such effort to compress the 17 million lines of JSF software code failed to yield development-cost efficiencies and instead revealed that several JSF capabilities required deferral in order to stay within

¹¹⁸ Ibid.

¹¹⁹ Senate. *Testimony Before the Subcommittee on AirLand, Committee on Armed Services—Tactical Aircraft F/A-22 and JSF Acquisition Plans and Implications for Tactical Aircraft Modernization, Statement of Michael Sullivan, Director Acquisition and Sourcing Management Issues, Government Accounting Office*. 109th Cong. 1st sess., 2005, On-line, Internet, 6 May 2005. available from <http://www.gao.gov/new.items/d05519t.pdf>

existing budgetary and scheduling constraints.¹²⁰ Additionally, persistent uncertainty from the military services regarding the number and mix of variants planned for purchase added to the complexity of the JSF procurement strategy. Projected STOVL purchases, in particular, fluctuated continuously as the Air Force announced intentions to field both CTOL and STOVL variants.¹²¹ Furthermore, the lack of formal agreements confirming FMS purchases added to the complexity in projecting near-term development and production costs.

Procurement quantities have decreased



Source: GAO analysis of DOD data.

Figure 14¹²²

Total program acquisition unit costs have increased

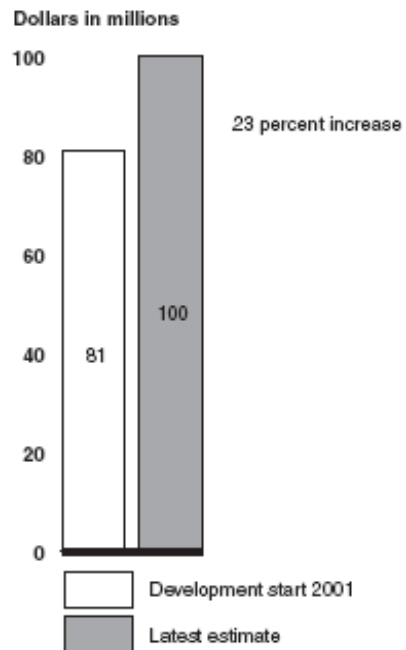


Figure 15¹²³

Front-Loaded Procurement Approach

The JSF program abandoned its original procurement strategy based on evolutionary acquisition principles in favor of a front-loaded schedule which committed to delivering full capability during the system-development phase. The debate regarding the merits and shortfalls of both strategies was central to near-term budgetary requirements for the JSF acquisitions program. Furthermore, the total life-cycle

¹²⁰ Ibid.

¹²¹ Ibid.

¹²² Ibid, 12.

¹²³ Ibid.

sustainability of the program became dependent on initial decisions regarding procurement schedules. Critics of the front-loaded strategy asserted that the JSF would not acquire adequate knowledge with respect to technologies, design, and manufacturing processes within the its system-development-and-demonstration phase, and have scaled back production to accommodate future system evolutions. Conversely, advocates pointed to the urgency of achieving full-system capability as early as possible in order to leverage a larger share of the DoD modernization budget for fleet production. Figure 16 provides a comparison between a best-practice scenario and that proposed for the JSF program, and depicts the scheduling overlap between JSF development and its planned low-rate initial production (LRIP) schedule.

Due to the overlap between system development and initial production projections, acquisitions officials in 2005 faced the choice of further delaying JSF procurement to allow for full development of technological capabilities or proceeding with 2007 LRIP activities. Despite the DoD's preference for the evolutionary procurement approach, the JSFPO has committed to the delivery of full-system capability at the end of its development phase by scheduling production for 20 percent of its total buys during the same period.¹²⁴ This decision fits well within the context of constrained defense budgets, particularly considering Congressional reluctance to fund long-term aircraft development and production efforts that yield little evidence of measurable real-world operational potential. While political realities force the JSF to jockey for scarce modernization dollars, the long-term impact of the front-loaded acquisition strategy would surface as the JSF required sustainment support to assure service-life viability. As discovered with its predecessor, the F-16, the absence of a sustainment strategy can pose significant challenges to an aging aircraft fleet. As shown in the previous chapter, quantitative modeling provides a means to address mid-late life-cycle JSF sortie capacity shortfalls and identifies necessary fleet requirements.

¹²⁴ Ibid.

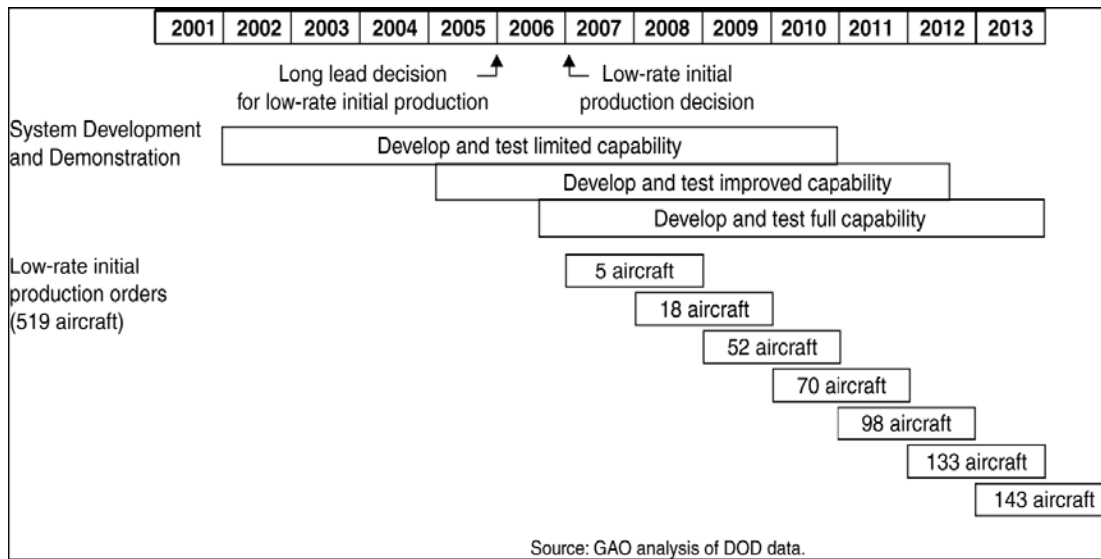


Figure 16: Overlap of JSF Low Rate Production and System Development and Demonstration Activities¹²⁵

State of the F-35 World—From a Modeling Perspective

A May 2005 draft of the USAF edition of the LRIP Performance Based Agreement unveiled the maintenance metrics formulated to support readiness requirements for JSF operations. This draft PBA established a contractual relationship between the JSF Program Executive Office (PEO) and the USAF as well as stipulated performance metrics that justify sustainment funding for the initial JSF production increment.¹²⁶ Of particular note, the proposed metrics served as the baseline performance measures for a range of operational and support activities occurring during the early phases of the F-35 life cycle:

This PBA supports all contracts and memorandum of agreements [sic] that contribute to the readiness, availability, and reliability of the F-35 CTOL logistics and engineering support systems. It includes all post LRIP I delivery sustainment services such as material support, publications, aircraft introduction, systems engineering, site activation, support equipment, training, supply train management, Autonomic Logistics Information System [ALS], sustaining engineering, fleet management ... and software support.¹²⁷

As the analysis in Figure 17 depicts, the forecast 85 percent MC rate for the JSF in 2013

¹²⁵ Senate. <http://www.gao.gov/new.items/d05519t.pdf>

¹²⁶ Draft F-35 LRIP I Performance Based Agreement (PBA) Between the Joint Strike Fighter Program Office (JSFPO) and the United States Air Force (USAF) 20 May 2005.

¹²⁷ Ibid,2.

represented the baseline objective for sustainment funding to meet the projected flying-hour program when the aircraft began full-rate production.¹²⁸ Figure 17 assumes similar maintenance variables as the F-16 in lieu of undemonstrated F-35 performance and projects an average 2.1/100,000 hour service-life attrition rate. As such, the results of the notional modeling drill validate the 85 percent MC rate as evidenced by the 28.52 hourly utilization rate which meets the FHP with a considerable surplus. Of particular note is the absence of a JSF programmed-depot-maintenance requirement eliminated by predictive maintenance capabilities of ALS/PHM technologies. Figure 17 highlights the projected reliability of a fully-developed-and-tested JSF weapon system as it enters full-rate production (FRP).

¹²⁸ Email from ACC/JSF office confirming the MC rate objective for JSF Full-rate production, 25 May 2005.

Notional JSF fleet modeling forecast analysis

FY2013

USAF "PA" PROGRAMMATIC FACTORS:

Annual Flying Hours	21,636	(PFT)
Accident Attrition Rate	2.1	/100,000 Hrs
Acft in Depot-level Repair	5%	(BAA)

AETC Maint & Ops Variable Factors:

Mission Capable (MC) Rate	85%
Scheduled Maintenance	25%
Phase	5%
Depot	0%
Preflighted Spare Aircraft	15%
Sorties per Aircraft per Day	2
Flying Days per Month	20.4
Night & Cross-Country Sorties	0.0%
Weather Losses	
Operations Losses	
Total Losses	3.0%
A/C Availability Tgt	93.0%
TNMCS	7.0%
NMCM 3yr. historical avg.	8.0%
NMCM historical avg.	2.0%
Sortie Length (Hrs)	1.4

Computed Operational Capability:

Primary Aircraft Inventory (PAI)	71
Daily Flyable Aircraft	57
Daily Scheduled CAP	37
Daily Scheduled CAP + Spares	43
Sorties/Day	73
Day Sorties/Month	1491
Day+Night Sorties/Month	1491
"Effective" Sorties/Month	1446
Flying Hours/Month	2025
Utilization Rate (Sorties)	20
Utilization Rate (Hours)	28.52

Capability vs Requirement Computation (PAI Driven):

Annual Flying Hour Capability	24,301
Annual Flying Hour Requirement	21,636
<i>Delta</i>	2,665

Aircraft Calculation:

Remarks:

Primary Aircraft Authorization (PAA)	71	29 Hours/Month per PAA Acft
Backup Aircraft Authorization (BAA)	4	5% Aircraft in Depot Maintenance
BAI Attrition Reserve (BAI-AR):	9	0.45 Class "A" Accidents per year
Total Aircraft Authorization (TAA)	84	Authorized Aircraft
Total Aircraft Inventory (TAI):	84	Aircraft Procured

Figure 17

Notional JSF fleet modeling forecast analysis **FY 2019**

USAF "PA" PROGRAMMATIC FACTORS:

Annual Flying Hours	191,016	(PFT)
Accident Attrition Rate	2.1	/100,000 Hrs
Acft in Depot-level Repair	5%	(BAA)

AETC Maint & Ops Variable Factors:

Mission Capable (MC) Rate	76%
Scheduled Maintenance	25%
Phase	5%
Depot	0%
Preflighted Spare Aircraft	15%
Sorties per Aircraft per Day	2
Flying Days per Month	20.4
Night & Cross-Country Sorties	0.0%
Weather Losses	
Operations Losses	
Total Losses	3.0%
A/C Availability Tgt	84.0%
TNMCS	16.0%
NMCM 3yr. historical avg.	8.0%
NMCB historical avg.	2.0%
Sortie Length (Hrs)	1.4

Computed Operational Capability:

Primary Aircraft Inventory (PAI)	629
Daily Flyable Aircraft	454
Daily Scheduled CAP	290
Daily Scheduled CAP + Spares	341
Sorties/Day	579
Day Sorties/Month	11812
Day+Night Sorties/Month	11812
"Effective" Sorties/Month	11458
Flying Hours/Month	16041
Utilizations Rate (Sorties)	18
Utilization Rate (Hours)	25.50

Capability vs Requirement Computation (PAI Driven):

Annual Flying Hour Capability	192,490
Annual Flying Hour Requirement	<u>191,016</u>
<i>Delta</i>	1,474

Aircraft Calculation:

Primary Aircraft Authorization (PAA)	629
Backup Aircraft Authorization (BAA)	31
BAI Attrition Reserve (BAI-AR):	<u>80</u>
Total Aircraft Authorization (TAA)	741
Total Aircraft Inventory (TAI):	741

Remarks:

26 Hours/Month per PAA Acft
 5% Aircraft in Depot Maintenance
 4.01 Class "A" Accidents per year
Authorized Aircraft
 Aircraft Procured

Figure 18

The UTE rate sensitivity caused by the MC rate adjustment in Figure 18 provides a notional look at the relative sortie-capacity sensitivity to MC rate fluctuations.¹²⁹ As contrasted with Figure 17,, the JSF fleet sortie capacity in Figure 18 is also well above the flying-hour requirement despite the 10-percent MC-rate reduction. This highlights an obvious reality regarding early life-cycle weapon system sustainment: *a new highly-reliable aircraft can operate at a lower MC and higher TNMCS rates and still meet FHP requirements.* While this discovery may amount to a *blinding flash of the obvious* for most aircraft logisticians, it questions the decades-long organizational practice of using MC rate standards as performance metrics for wing-level maintenance organizations. In addition to the benefits of high aircraft reliability, the underutilized BAI aircraft availability can also offset the effects of high NMC rates for an early life-cycle weapon system. As mentioned earlier, BAI aircraft are fielded for the expressed purpose of supplementing PAI strength depletions due to unscheduled depot maintenance and fleet-wide modifications. For an early life-cycle weapon system with high reliability however, BAI capacity is typically sub-optimized but could provide additional capacity in the event of a diminished maintenance capability due to low TNMCM and TNMCS rates.

TLCS-A New Approach

The USAF has traditionally used fleet-specific MC rate standards to justify operating and support costs for fiscal-year defense budgets as well as for performance measurements for wing-level maintenance organizations. The latter purpose, however, neglects to account for the unpredictability of long-term defense spending and ignores the potential early life-cycle reliability benefits afforded by fully-developed and operationally-tested weapon systems. Whereas the fleet-wide MC-rate standard is useful toward Operations and Support (O&S) costs for annual budget justifications, it lacks relevance as an optimization tool for unit- level maintenance performance. Conversely, over the long term, the legislation of a performance-motivated MC-rate standard can deplete a weapon system's support infrastructure and risk late-life-cycle sustainability. A *variable* MC rate standard tailored to FHP requirements, however, could leverage early life-cycle aircraft reliability to mitigate costs of future sustainment demands. In addition

¹²⁹ Figures 17 and 18 derived from sensitivity model produced SMSgt (ret.) Mike Wasson, AETC Studies and Analysis. Data obtained from ACC DRA/JSF CTOL Beddown plan for the FY'06 POM

to the excess flying-hour capacity caused by the higher MC-rate standard depicted in Figure 17, the necessary level of sustainment necessary to attain the 85 percent MC standard is significantly higher than the minimum required to meet the FHP objective as shown in Figure 18 (76 percent).

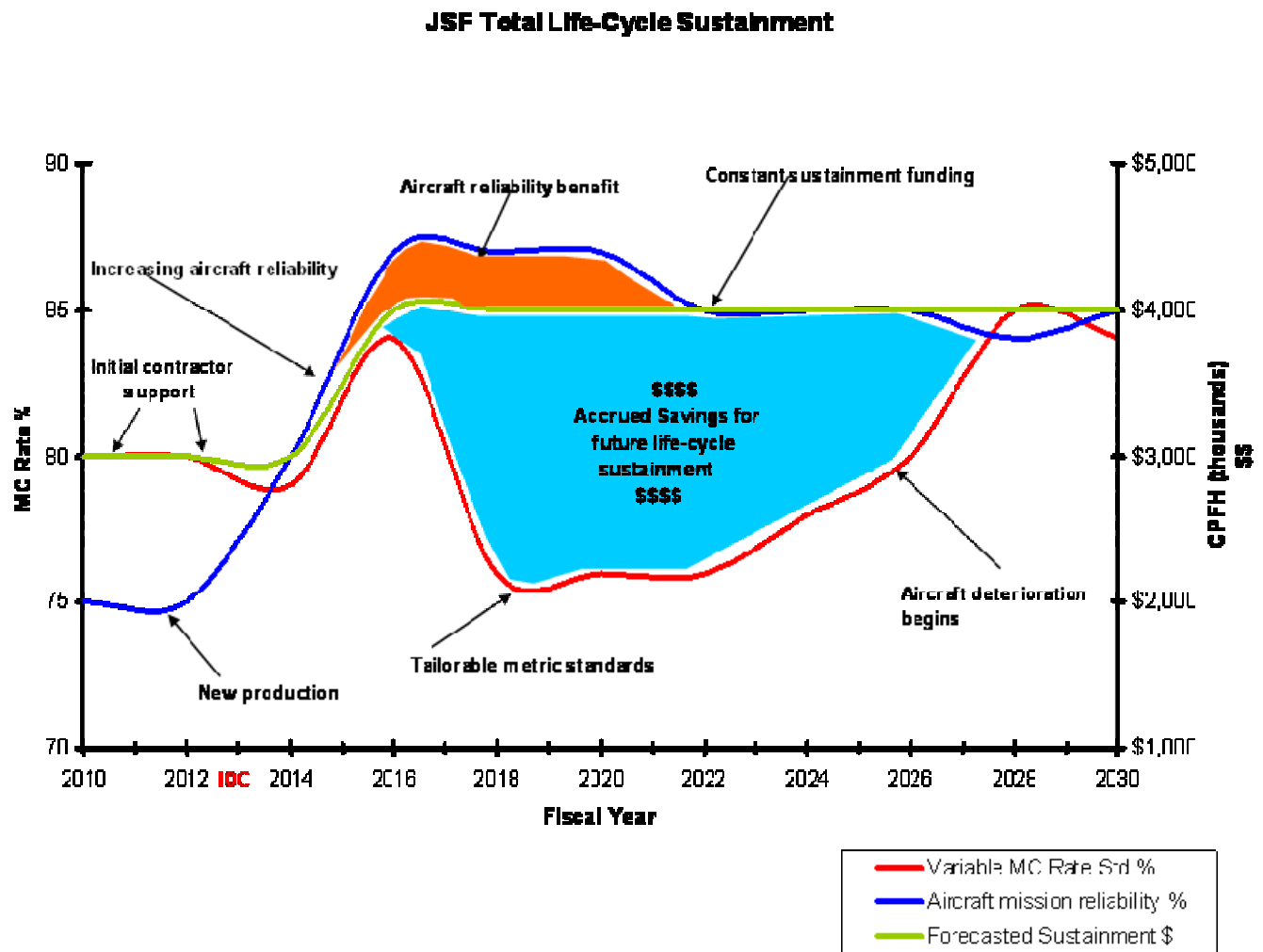


FIGURE 19¹³⁰

This phenomenon demonstrates the reliability benefit and subsequent savings gained from a growing fleet size, underutilized BAI assets, and lower operating-and-support

¹³⁰ Produced by author from ideas generated during thesis discussions with Dr. Stephen Chiabotti Vice Commandant, School of Advanced Air and Space Studies. Data obtained from ACC DRA/JSF and JSFPO. As of this writing, CPFH projections are considered sensitive information. Data depicted is an estimate of F-35 CPFH costs based on a stated JSFPO goal of achieving an F-35 flying-hour costs below that of the average F-16 rate over its life-cycle.

(O&S) costs of early-production aircraft. Therefore, the savings accrued through the establishment of tailorable maintenance metrics standards designed to *adequately* meet FHP performance levels, particularly during early phases of an aircraft's service-life, can potentially defray future costs accompanying late-cycle aircraft deterioration.

In Figure 19, a JSF Total Life Cycle Sustainment (TLCS) model is proposed consisting of three weapon system life-cycle forecast curves for aircraft reliability, sustainment funding, and maintenance performance. The purpose of this model is to depict the effects of tailorable MC-rate standards on aircraft reliability (blue-line) given a constant rate of sustainment funding throughout a weapon system's life cycle. Whereas, current sustainment-funds programming fluctuates annually based on weapon-system performance, price indices, and near-term operations-tempo projections, the TLCS recommends a sustainment funding stream (green-line) based on forecasted cost-per-flying-hour and specified O&S expenses. Furthermore, the TLCS model leverages opportunities to invest underutilized early life-cycle funding towards future life-cycle sustainment requirements by setting maintenance performance standards to meet FHP demands as opposed to performance goals (red-line). The savings generated from this tailored approach are then managed in a financial instrument similar to existing DoD working capital funds (WCF) which provide for weapon system sustainment based a revolving-revenue concept. The TLCS approach ultimately offers the following benefits:

1. a "just in time" sustainment approach that provides the necessary infrastructure when needed
2. early investment to maximize future buying power
3. protection against unexpected defense-budget cuts and a shift in the organizational focus away from maintenance optimization to FHP requirements.

Although the JSF TLCS is notional, it assumes two conditions based on historical evidence from previous tactical aircraft acquisitions programs: 1. aircraft reliability is higher during early life-cycle years and subsequently decreases over time and 2. aircraft sustainment costs increase over time due to aging and pricing factors. Figure 19 highlights these ebbs and flows which occur over a weapon system's life cycle and offers a methodology to take advantage of early life-cycle performance to protect against late life-cycle deterioration and rising costs.

While this approach proposes a methodology to overcome future aircraft life-cycle sustainment challenges, the TLCS model must also account for the existing organizational programming and budgeting culture which employs an execution-year versus total-life-cycle mindset. In order for the TLCS approach to work in practice, the DoD must shift its current organizational paradigm to accommodate a total life-cycle investment approach based on weapon-system performance forecasts. The following discussion provides recommendations on how to meld the TLCS model into existing DoD standard operating procedures.

TLCS—From Rhetoric to Reality

Currently, the DoD forecasts O&S expenses which include purchases for fuel, lubricants, repair parts, depot maintenance and contract services, and modification-kit procurement and installation based on price indexes, demand rates, and historical weapon-system performance.¹³¹ As shown in Figure 20, these collective factors represent approximately 70 percent of total life-cycle costs for a given weapon system.¹³² Of this 70 percent, the cost volatility associated with depot-level repairable and consumable parts account for a significant portion of O&S expenses.¹³³ Additionally, the unpredictability of repairable and consumable parts costs present challenges to budgetary forecasting causing unpredictable fluctuations in fleet-wide CPFH rates. These conditions result in increased O&S costs, additional supplemental budget requests, and delayed maintenance when funding shortfalls fail to provide for sustainment requirements. Program managers collectively identify the need to develop internal cost-reduction efficiencies in order to control O&S expenses and thwart the effects of external cost fluctuations:

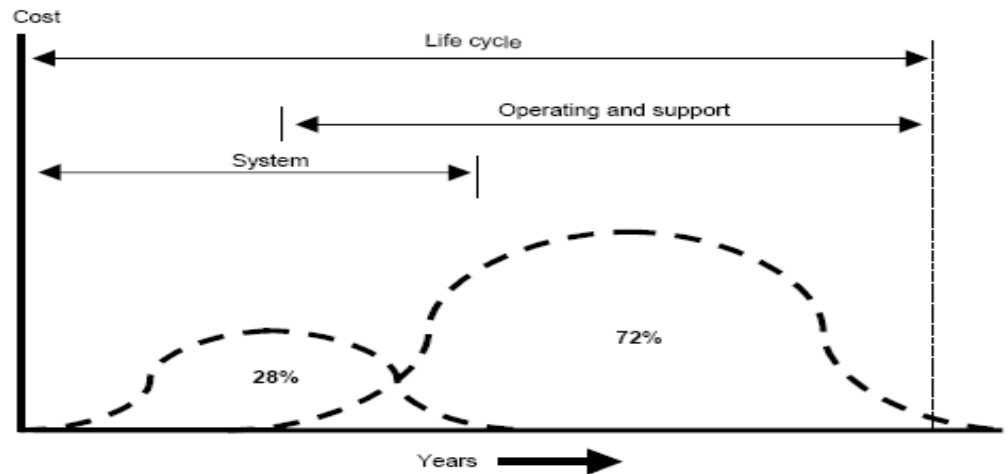
...repair parts are the top candidates for cost reductions because new and more reliable parts and processes can be designed and manufactured to replace parts that fail often or are difficult to obtain. More reliable parts fail less often and require less maintenance. For example replacing the [existing] F-16 battery with a maintenance-free battery [costs] \$3.4 million

¹³¹ Senate, *Report to the Chairman and Ranking Minority Member, Subcommittee on Readiness and Management Support, Committee on Armed Services—Defense Acquisitions—Air Force Operating and Support Cost Reductions Need Higher Priority*, August 2000, 3-6, On-Line, Internet, 20 May 2005, available from <http://www.gao.gov/new.items/ns00165.pdf>.

¹³² Ibid, 6.

¹³³ Ibid.

fleet wide and [will] save \$3.8 million over the next nine years and \$6.9 million over the next 25 years.¹³⁴



Source: Defense Systems Management College Acquisition Guide.

Figure 20: Nominal life cycle cost of A 1980 Acquisition Program with 30 year service life¹³⁵

Cost-reduction strategies for repair parts, consumable items, and depot-maintenance activities are essential to insuring the projected service life of a weapon system. The JSF, due to its joint development and employment, will likely present significant sustainment challenges stemming from the sheer size of the program. Despite efforts to build commonality into the different aircraft variants, the viability of the advanced systems employed by the JSF will demand constant vigilance to ensure that costs for repair parts and maintenance activities remain under control. Because the JSF TLCS methodology is an investment-based approach to funding late-life cycle sustainment requirements, it depends on cost-reduction initiatives gained through increased parts reliability and inexpensive repair processes that ultimately reduce CPFH rates fluctuations. Furthermore, greater savings protect sustainment forecasts against unforeseen events such as aircraft modifications, contingency operations, and design anomalies which incur additional life-cycle costs.

So, just where do the savings produced via the TLCS methodology go? The DoD currently manages an intricate web of working capital funds (WCF) designed to “provide a financial structure that is intended to promote total cost visibility and full cost recovery

¹³⁴ Ibid, 9.

¹³⁵ Ibid, 6.

of support services.”¹³⁶ Whether the JSFPO decides to utilize an organic sustainment infrastructure or one provided through Contractor Logistics Support (CLS), an *adaptable* WCF construct is applicable as a viable mechanism to manage appropriated resources for weapon system life-cycle sustainment. According to DoD costing officials:

The funds are structured around functions that provide goods and services to customers throughout DoD. Managers of these functions prepare their proposed budgets based on anticipated workload and expenses. At the same time, fund customers include in their budgets their planned requirements for goods and services from the various functions. These budgets are submitted ... and the budget process set rates for each function. Rates are keyed to a unit of output that are unique to each function. The rates are stabilized for the year and are intended to endure that customers pay for the full cost of goods and services they receive from the functions.¹³⁷

Two WCF funds which currently support aviation sustainment requirements are the Depot Management Activity Group (DMAG) and the Supply Management Activity Group (SMAG). As stated earlier, these financial instruments operate under a revolving fund concept “of breaking even over time by charging customers the full costs of goods and services provided to them.”¹³⁸ Customers such as MAJCOM wing organizations use appropriated Operations and Maintenance (O&M) funds to purchase the goods and services provided by the WCFs. The activity groups then use revenues to replenish inventory and pay labor costs for rendered services.¹³⁹

To enable the TLCS framework, a WCF-type instrument would continue to manage financial activities associated with providing sustainment support to operational units, however, TLCS revolving funds would institute a predictive, versus reactive, sustainment approach for managing specified categories. For example, current WCFs are initially funded by Congress to build an inventory of parts or sustain a workforce organization. Once the initial infrastructure is established, customers use unit-level annual O&M funds to pay for inventory items and labor costs for stated requirements.

¹³⁶ Unites States Air Force Annual Financial Statement 2003, On-line, Internet, 20 May 2005. available from <http://www.dodig.osd.mil/audit/reports/FY04/USAF2003finstmts.pdf>, 15

¹³⁷ Ibid, 15.

¹³⁸ US House. Report to the Chairman, Subcommittee on Military Readiness, Committee on Armed Services, House of Representatives—Air Force Supply—Management Actions Create Spare Parts Shortages and Operational Problems, On-Line, Internet, 20 May 2005. available from <http://www.gao.gov/archive/1999/n199077.pdf>, 14.

¹³⁹ Ibid.

These O&M payments serve as revenue for the WCFs and are subsequently used to replenish inventory stockage levels, pay salaries, and recoup administrative costs associated with providing goods and services. Conversely, a TLCS WCF would receive a projected *total* life-cycle sustainment appropriation, phased in lump sums over several multiple Future Years Defense Program (FYDP) periods, from Congress to manage fleet requirements throughout an aircraft's entire service life. This sizable investment would sit in an interest-bearing financial instrument attached to US government securities, such as T-Bills, with authorization to reinvest gains. In the case of the jointly-employed JSF, a DoD Program Executive Office would manage this fund and authorize all expenditures to support operational requirements for each of its military service customers.

Under this centralized sustainment construct, TLCS WCF representatives from each service would coordinate maintenance performance standards with respective operational command organizations and tailor sustainment support to fulfill FHP requirements. During contingency operations, the TLCS WCF officials would coordinate with the operational commands to request appropriate supplemental funding to replenish inventory and workforce capabilities exhausted by the unforeseen operational requirements. The advantage in this approach is accountability for providing weapon system life-cycle sustainment rests with a centralized organization charged with monitoring fleet health and distributing responsive logistics support, as outlined by Agile Logistics program initiatives.¹⁴⁰

While this approach transfers control for life-cycle sustainment from unit-level wing organizations to a centralized PEO, it utilizes the benefits derived from evolutionary JSF ALS/PHM technologies to leverage predictive maintenance capabilities to preemptively, versus reactively, address aircraft deterioration. Additionally, the TLCS methodology leverages the advantages of financial discounting to increase the buying power of sustainment dollars over a 20-30 year aircraft service-life period. The TLCS WCF construct provides an adaptable programming and budgeting vehicle to accommodate the necessary shift from execution-year to total life-cycle sustainment without sacrificing operational performance.

¹⁴⁰ Agile Logistics is an initiative developed to streamline the USAF parts repair process by eliminating warehousing of DLRs between operational units and depot repair facilities.

The F-16 program sustainment crisis provides ample proof that a failure to address total life-cycle sustainment requirements can cause significant challenges as aircraft age due to operational demands and unpredictable funding. Due to the sheer size of the F-35 joint acquisition, current approaches to life-cycle sustainment will not accommodate the myriad of challenges associated with the disparate aircraft variants and the corresponding range of service operational requirements. TLCS is a step toward instilling the culture of accurate weapon system forecasting within the DoD and Air Force while shifting the focus towards tailorable performance standards designed to meet appropriated flying-hour program requirements. By advocating that weapon system programs pay for themselves over time through the establishment of efficiency-based performance standards based and stringent reliability controls, the JSF TLCS offers promise to meet projected service-life goals while minimizing costs.

Conclusion

Scientists and engineers are rarely familiar with the detailed tactical contents of the military requirements that are imposed on them. In any case, their obedience to those requirements is often formal: they know very well that military requirements change with each new tactical doctrine, each new “strategy,” while the weapons they develop last for many years—thirty years or more for combat aircraft, even longer for tanks and guns. Scientists and engineers, moreover, tend to have little respect for requirements formulated by military authorities whom they often see as ignorant of the full range of technological possibilities open to them ... The ever increasing technological education of military men (it started in the eighteenth century) has not closed the divide because the sides are subject to different authorities: science itself for scientists and engineers, military institutions and hierarchies for soldiers.

Their purposes are essentially divergent. For military bureaucracies, the maximum quality that can be achieved in a single weapon system is usually sacrificed for the sake of quantity ... For scientists and engineers, numbers have no value at all in themselves: maximum quality is the only goal of their ambition.

—Edward N. Luttwak
Strategy—The Logic of War and Peace

This thesis proposes two central research questions: How do sortie generation, supply, and maintenance factors affect weapon fleet size and long-term life-cycle sustainability? Can good planning effect economies and efficiencies? The analysis of a historical case study and the development of new life-cycle-sustainment approach answer both questions affirmatively. There are, however, future implications of the TLCS framework and areas for additional research.

The Way Ahead

The TLCS approach is a counterintuitive way of thinking about preserving aircraft service-life. If viewed from a *glass is half-empty* perspective, it sub-optimizes aircraft maintenance capability performance in an effort to assure long-term life-cycle sustainment. This perspective, however, is a narrow assessment and fails to consider the

original two assumptions established at the beginning of this thesis: 1. a positive correlation exists between aircraft age and sustainment costs and 2. a highly-reliable aircraft's mission-capability performance is tailorable to operational flying-hour program requirements. Given these conditions, the TLCS offers a framework that both optimizes efficiency and maximizes effectiveness for an aircraft weapon system's operations-and-sustainment life-cycle.

Policy Implications

Because the TLCS model proposes a fundamentally different approach, its implementation will require changes and procedural accommodations with respect to DoD procurement and Congressional appropriations policies. Current programming and budgeting practices, based on an execution-year mindset, are not sufficient to address aircraft life-cycle challenges which sometimes span two decades or more. Additionally, government contracts do not include provisions to incentivize future life-cycle savings accrual through increased weapon system reliability and efficient repair-cycle management.

Inherently, the TLCS approach shifts the burden of life-cycle sustainment to the ultimate user of the weapon system. Whereas, the current mindset depends on the annual assessment of sustainment funding requirements based on operational performance, a TLCS approach seizes the opportunity to internally control weapon system performance in order to leverage early-life-cycle reliability. As such, a TLCS sustainment strategy pays for itself in the long-run, and mitigates the need for significant late life-cycle recapitalization.

Additional Research

The TLCS framework is one of several attempts to resolve Air Force's weapon system sustainment problem. Unfortunately, a thesis-length work is insufficient to develop the idea completely. Thus, two important areas remain for further research. TLCS implementation requires a thorough analysis to develop an organizational process to manage its proposed financial components. Most financial procedures within the DoD are restricted by legal controls which may currently prohibit the long-term management

of weapon-system sustainment funding. Furthermore, the DoD needs to construct an investment instrument to maximize the potential of savings accrual in accordance with TLCS principles.

Another area of research ripe for exploration is an assessment of the methodology used to determine Air Force aircraft maintenance metrics. During the course of this project, numerous Air Force logistics organizations were asked to define the criteria used to determine mission-capable-rate standards to establish maintenance capability goals. Surprisingly, the criteria varied greatly between the respective major command organizations as well as within the Air Staff maintenance directorate. This lack of standardization highlights a potential disconnect between the criteria used to determine flying-hour program and maintenance-capability requirements, which could lead to inefficient aircraft fleet management practices.

Conclusion

As the world's most powerful air force, the USAF depends on superior technology, organization, and industrial support to project air and space power globally to defend American interests and values. Innovation, not only in weapon system development and tactics but also in organizational design and management methods, is essential to maximizing the effectiveness of airpower employment in the current dynamic geopolitical environment. The melding of procurement, operations, and logistics activities is critical to sustaining military supremacy.

In *Strategy—The Logic of War and Peace*, Edward Luttwak advances the claim that the “entire realm of strategy is pervaded by a paradoxical logic very different from the ordinary “linear” logic by which we live in all other spheres of life.”¹⁴¹ In the future, military strategists will look continue to look toward paradoxical solutions to address the complex and unconventional challenges of Twenty-First Century warfare. The TLCS is just one example of the paradoxical nature of preparing for and conducting warfare.

¹⁴¹ Edward Luttwak. *Strategy—The Logic of War and Peace* Cambridge, Mass.: Harvard University Press, 2001), 2.

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